N71-14637

NASA CR-115879

# ANNUAL REPORT OF ACTIVITIES SUPPORTED BY AND RELATED TO NASA GRANT NGL 44-004-001

MULTIDISCIPLINARY RESEARCH IN SPACE-RELATED SCIENCE AND TECHNOLOGY



1 DECEMBER, 1970

THE UNIVERSITY OF TEXAS AT DALLAS

POST OFFICE BOX 30365 DALLAS, TEXAS 75230

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This research program is carried out at

The University of Texas at Dallas
P. O. Box 30365
Dallas, Texas 75230

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# I.

## General Objectives

The University of Texas at Dallas came into existence September 1, 1969, when the Southwest Center for Advanced Studies was given to The University of Texas System to form the nucleus of the new university. The new university is classified as a general educational institution. Initially, it will be involved in graduate programs only, and these are being implemented as they are approved by the Board of Regents of The University of Texas System and by the Coordinating Board, Texas College and University System. Undergraduates will enter the system in 1975. The first graduate programs have been established in physics (including atmospheric and space physics), geophysics, and molecular biology.

The Southwest Center for Advanced Studies was formed in 1961 to assist in the development of graduate education in the Southwest. From its inception, SCAS was unique as an educational institution in that it presented a multidisciplinary approach in organization rather than the classical departmental structure. We use cadres termed divisions whose faculty members represent several major scientific disciplines working together in probing problems of basic research. A number of cooperative programs have been developed with other educational institutions, and these are continuing under The University of Texas at Dallas. The Atmospheric and Space Sciences Division serves as the Space Sciences Center of the Institute of Technology at Southern

Methodist University. The Geosciences Division has been engaged in a joint doctoral program with Southern Methodist University for several years, in which the Geosciences faculty has served as part of the SMU faculty. Under a new agreement reached in 1968, a new joint program was undertaken in which students are accepted at SCAS, now The University of Texas at Dallas, although registering at SMU, but with primary responsibility for the student residing at this institution. Both of these Geosciences arrangements are working simultaneously. In the area of relativity and cosmology, several students from The University of Texas at Austin have undertaken and completed their thesis research at Dallas. Other somewhat similar arrangements have been utilized, or are under way, with several other schools in the Southwest, including North Texas State University, Texas A&M University, and Oklahoma State University.

Several private institutions in the North Texas area have joined together in The Association for Graduate Education and Research (TAGER). Participant Institutions of this association are The University of Texas at Dallas, Southern Methodist University, Texas Christian University, Dallas Baptist College and the University of Dallas. Associate Participant Institutions include Austin College, Texas Wesleyan College, and Bishop College. These institutions are joined by closed circuit, microwave link television for exchange of courses and seminars, primarily in science and engineering at the graduate level. Receiving locations also exist in many industrial laboratories or plants in the area. The office of TAGER and its television central switching station are located on the campus of The University of Texas at Dallas.

The NASA Sustaining Grant has been very helpful in the development of the research program at our institution. It has contributed to a space orientation in the program and has served to keep a significant portion of the staff involved in the NASA scientific program. This has resulted in a productive cooperation between The University of Texas at Dallas and several NASA centers and programs.

The general objective of the NASA-supported program is to develop an understanding, on an interdisciplinary basis, of the structure of the solar system and its components, and evolutionary paths by which the present organizational state was reached.

## II.

## Research Program Supported by Grant

The overall research objective of the earth and planetary program at UT Dallas is to develop as completely as possible an understanding of the planets, including their atmospheres and the processes by which they have reached their present stages of development. The scope of activity ranges from cosmology to detailed interactions of the planets with their environments. The characterizing feature of the entire research program is its breadth or multidisciplinary nature, which enables each research effort to draw strength from other areas around it.

In addition to the basic grant, supplemental funding from the Program Offices has been provided through the grant instrument since April 1964; this supplemental funding has provided additional support for specific portions of the program. Further, there are many contracts with NASA for specific experiments to be performed in rockets or space vehicles. Brief mention of those activities supported by NASA contracts, or by other agencies where the results are especially relevant to NASA interests, are made in a later section of this report. In this section, the activities supported by the grant are described. Since the research areas are frequently highly interrelated, their breakdown by subject headings is arbitrary, but some such division is necessary for convenience in describing the programs.

1. Origin of Planetary Atmospheres

F. S. Johnson

(a) Prospect of observing lunar gas release

As indicated in other reports, there is ample evidence that gas release from the planetary interiors is the source of planetary atmospheres (for the inner or terrestial planets at least). The rate of release can be estimated from the total release assuming it to be uniform over geologic time, but no means has been recognized of estimating accurately the present rate of release if it is different from the average rate. The moon may offer an opportunity to estimate the present rate of release there. This is so because escape is relatively rapid and release is apt to be intermittent, providing an opportunity to estimate the release rate as accurately as the escape rate can be evaluated.

The prospect of observing intermittent gas release on the moon appears to be reasonably high, based on the frequency with which seismic activity has been observed there. The activity is concentrated near the time of perigee, suggesting that it results from gravitational stresses on the moon. Such straining of the moon, leading to seismic activity, should be accompanied by a release of gas which is recognizably different from the gas delivered to the moon by the solar wind.

The gas concentrations to be found on the moon, whether from internal or solar wind origin, may at times be greater than hitherto thought because of the tendency for gases to concentrate on the cool, dark side of the moon. This substantially increases the average lifetime for gas particles on the moon. Gas concentrations on the dark side of the moon are apt to be as much as 30 times greater than on the light side. Since only a relatively small part of the light side of the moon is hot and conducive to rapid escape, the lifetimes of particles are enhanced by even greater factors. These factors are now being evaluated.

R. R. Hodges

(b) Lunar exospheric transport

Studies of exospheric transport have generally been based on a crucial assumption: that the exobase, where the ballistic trajectories of exospheric particles originate and terminate, can be approximated as a surface of constant geopotential. For the terrestrial exosphere this assumption implies neglect of the influence, on particle trajectories, of collisions in a layer of atomic oxygen of about an oxygen scale height in thickness (ca. 50 to 100 km). In contrast, the gas pressure at the surface of the moon is so low that the surface forms the base of an almost classical exosphere. Thus it might be expected that exospheric fact and theory should be more closely correlated on the moon than on earth.

The current accessibility of the moon in the Apollo program, and the eventual acquisition of mass spectrometric data on the composition of the lunar atmosphere, suggest the importance of a reexamination of exospheric transport theory in terms of phenomena thought to be peculiar to the moon. The simplest cases are the diurnal tidal oscillations of neon and argon, which escape slowly and are unlikely to be affected by surface adsorption. Neon is expected to be essentially in static equilibrium, with a surface concentration that varies as $T^{-5/2}$, resulting in a night to day ratio of about 30 to 1. Argon is heavier and more noticeably influenced by rotation of the moon; its nighttime surface concentration maximum is expected to be slightly shifted toward sunrise so that the argon concentration at the sunrise terminator should exceed that at sunset by about a factor of two. Other slowly escaping gases (i.e. excluding H and He) are probably adsorbed on the cold night time surface (about 100°K), and then carried by rotation of the moon to the sunrise terminator where release occurs rapidly from the warming sunlit surface, forming a sunrise pocket of gas. (These phenomena are discussed by Hodges and Johnson, 1968).

In addition to diurnal variations, it is expected that other temporal phenomena may be detected on the moon. Of selenologic interest are transients due to natural volcanic release of gases or from meteor impact. Man-made transients, originating from spacecraft rocket firings, space vehicle impact with the surface, or grenades of active seismic experiments, should also be detectable, and may serve as calibration tests for the analysis of natural transients.

The only practical analyses of transients in the lunar atmosphere must come from measurement of the flux of downcoming particles at the surface. Horizontal motions in a transient particle distribution must necessarily be anisotropic, since a transient implies flow away from a source, and thus detection of a single horizontal component of the particle flux defies accurate interpretation.

In current research at The University of Texas at Dallas, a number of features of the propagation of lunar atmospheric transients are beginning to emerge. For example, the usual diffusion models of exospheric transport appear to be applicable only to problems in which scales of distance are large as compared to a scale height (the order of 100 km) and scales of time are large as compared to the mean time of flight of ballistic particles (the order of several hundred seconds). This rules out their application to a volcanic release of gases, which is thought to be representable as a point source, and necessitates a more complicated, exact theory. The latter is obviously quite complicated in general, but in the special case of an impulsive point source on the cold dark side of the moon, where surface adsorption should remove virtually all downcoming molecular gases, the transient response of the downward flux of a gas is

$$\frac{1}{8\pi H^2 t} \exp\left( - \frac{\pi}{4}\left(\frac{t}{\tau}\right)^2 - \frac{1}{\pi}\left(\frac{r}{2H} \cdot \frac{\tau}{t}\right)^2 \right)$$

where r is radial distance from the source, H is scale height corresponding to the source temperature and $\tau$ is a characteristic time of flight given by

$$\tau = \frac{4H}{\langle v \rangle}$$

and $\langle v \rangle$ is mean particle speed. This function has a maximum which propagates like an outgoing shock wave, except that its velocity of propagation is dependent on distance. Near a source ($r \ll H$) this velocity is $\frac{\sqrt{\pi H}}{2r} \langle v \rangle$, but far from the source ($r \gg H$) it becomes $\sqrt{\frac{\pi r}{4H}} \langle v \rangle$ (i.e. increasing as $r^{1/2}$). It is clear that this would preclude use of simple triangulation to locate a source if simultaneous operation of several mass spectrometers were feasible.

The characteristic time variation of the above transient response function, and its dependence on distance and particle mass suggest that simultaneous data from a single instrument for two gases with similar surface adsorption properties should be sufficient to determine both the distance of a source and the time history of the gas release. On the warm sunlit surface where adsorption is unlikely to be important, the exact theory is greatly complicated, requiring numerical analysis, and the only emergent analytical result is that far from a source the velocity of transient propagation decreases with distance as $r^{-1}$.

Reference

Hodges, R. R., Jr. and F. S. Johnson, "Lateral Transport in Planetary Exospheres," J. Geophys. Res., 73, 7307, 1968.

2. Atmospheric Structure

T. N. L. Patterson

(a) The global asymmetry of the exospheric hydrogen distribution

A program has been developed for the numerical calculation of the lateral flow of gases over a spherical surface. Application has been made to the flow of atomic hydrogen in the earth's exosphere. The escape of atomic hydrogen from the high regions of the earth's atmosphere plays a fundamental role in determining the altitude distribution of this gas. The rate of escape is well known to be a very sensitive function of temperature, with the result that, if hydrogen gas responded instantaneously to diurnal exospheric temperature variations, a day-night asymmetry as high as 20 in the concentration of hydrogen might be expected. Studies during the last few years have shown, however, that lateral flow of hydrogen gas in the exosphere will cause a considerable reduction in the magnitude of this asymmetry, a ratio of the order of 2 being much more likely.

Results have been presented at the IAGA Symposium in Madrid, Spain, and published in Rev. Geophys., 8, 461, 1970.

(b) Metastable helium

A theoretical investigation of the distribution and rate of excitation of metastable helium in the atmosphere has continued. The work was done in conjunction with an observational program and makes use of the powerful technique of model building to interpret experimental data. The observational data taken at Sorocco, New Mexico, show an intensity increase of a factor of 3 during the period 1967-1970 that is closely related to corresponding change in the solar EUV radiation ($\lambda$<380°A). There is a large seasonal variation caused in part by a 5:1 variation in the neutral helium abundance and augmented by seasonal variation in the conjugate photoelectron flux. In addition, a diurnal variation of the helium abundance of about 30% with a maximum in the morning appears to be present.

A paper giving a detailed description of the work is to appear in the Journal of Geophysical Research (Christensen, et al. 1971).

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Christensen, A. B., T. N. L. Patterson and B. A. Tinsley, "Observations and Computations of Twilight Helium 10830 Å Emission," submitted to the J. Geophys. Res., 1970.

Patterson, T. N. L., "Diurnal Variations in Thermospheric Hydrogen," Rev. Geophys., 8, 461, 1970.

J. P. McClure and W. B. Hanson

(c) The neutral exospheric temperature distribution at low latitudes

Based on incoherent scatter data obtained at the Jicamarca Radar Observatory, it has been inferred that at 12°S the midnight neutral temperature is approximately 14% warmer in summer than in winter. This is a much larger seasonal variation than that expected based on model neutral atmospheres. Both may of course be correct, as the model atmospheres indicate the average distribution of the neutral density.

The phase of the seasonal variation agrees with that expected on the basis of the suggestion of Johnson (1964) that the semi-annual variations in the neutral temperature may be caused by changes in the global circulation. The N-S temperature gradient across the equator, and hence presumably the circulation currents, reach a maximum in January and July, the months of the minima in the semi-annual temperature variation.

The radar data indicate that ion and neutral temperatures are closely coupled up to at least 500 km near the geomagnetic equator. Thus ion temperatures measured by suitable satellites should reflect the temperature values and temperature gradients predicted from the radar data. Preliminary data from the retarding potential analyser on OGO 6 (Hanson et al., 1970) seem to be consistent in both magnitude and gradient with the Jicamarca data. Thus it may be possible to map many features of the neutral temperature distribution from direct satellite measurements.

The OGO 4 satellite carried an instrument similar to but not identical with the OGO 6 instrument mentioned above (Chandra et al., 1970). The OGO 4 ion temperatures do not agree with the radar temperatures as closely as the OGO 6 values do. The OGO 4 temperatures were sometimes more than 40% higher than those inferred from the radar data. This work has been reported in a paper submitted to the Journal of Geophysical Research (McClure, 1970).

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Hanson, W. B., S. Sanatani, D. Zuccaro and T. W. Flowerday, "Plasma Measurements with the Retarding Potential Analyser on OGO 6," J. Geophys. Res., 75, 5483, 1970.

Johnson, F. S., Southwest Center for Advanced Studies, Report on Contract Cwb 10531, 1964.

McClure, J. P., "Thermospheric Temperature Variations Inferred from Incoherent Scatter Observations," submitted to the Journal of Geophysical Research, 1970.

3. Ionospheric Structure

J. E. Midgley

(a) Photoelectron induced potential discontinuities

In all the calculations made to date of the escape of the polar ionosphere, the plasma approximation ($n_i = n_e$) and the equation of hydrodynamics have been assumed to be applicable everywhere. The existence of photoelectrons has been acknowledged as contributing to an increase in the escape flux, but it has always been assumed that their effect could be properly taken into account simply by increasing the effective temperature of the electrons. Actually the electrons are not all relaxed to some effective temperature, but rather the situation is more accurately represented by assuming them to be a superposition of a large number of thermal electrons at one temperature and a smaller number of photoelectrons at some much higher temperature.

If one attempts to solve the hydrodynamic expansion problem for these three species (one type of ion and two types of electrons) it turns out that for certain ranges of the parameters the solution at some altitude becomes multi-valued, indicating that it is physically impossible to continue the solution beyond that point. Whenever such a condition occurs in the solution of a differential equation representing a physical system, it usually indicates that there will be some sort of a discontinuity in the physical system and that some approximation which holds in general outside the discontinuity will break down, allowing a rapid transition to a new set of variables from which the original type of solution can be continued. For instance, in a supersonic adiabatic gas dynamic flow, entropy is conserved in general. If, however, an obstacle is encountered or for some other reason isentropic flow cannot be continued, a shock is formed and all the entropy generation occurs in this thin discontinuity. On the other side of the discontinuity isentropic flow resumes.

In the problem under consideration, an electric potential discontinuity is formed in the flow and the approximation which is violated within the discontinuity is the plasma approximation ($n_i = n_e$). This requires a detailed solution of Poisson's equation ($\nabla^2\phi = \varepsilon_o e(n_e - n_i)$) through the discontinuity to determine permissible input parameters and the resultant output parameters. Fortunately, under the approximation that the electrons are massless and the ions are cold, Poisson's equation can be integrated exactly through the discontinuity and an implicit algebraic relation obtained for the permitted ratio of photoelectrons to thermal electrons for a given ion kinetic energy. For each such permitted combination of parameters a definite potential jump $\Delta\phi$ occurs and the hydrodynamic solution can be continued from that point.

Numerical work is now under way to define the ranges and relationships for all the significant parameters.

W. B. Hanson

(b) Molecular ions and the nightglow

The technique previously developed for studying F-2 region morphology (Hanson and Moffett, 1966; Sterling et al., 1969) has been extended to the nighttime F-1 layer by including quantitatively the chemistry and dynamics of the conversion of $O^+$ to $O_2^+$ and $NO^+$ at the bottom of the F-2 layer (Brasher and Hanson, 1970).

A numerical technique is employed in solving the coupled, non-linear system of equations for the $O^+$, $NO^+$, and $O_2^+$ number densities in the nighttime F-region, including the effects of diffusion, $\overline{E} \times \overline{B}$ drift, and neutral air motions. A "best fit" to the "sunset" and "midnight" rocket observations of the ion profiles obtained by Holmes et al. at White Sands, New Mexico, is achieved by iteratively varying the neutral wind, the electrodynamic drift, the neutral atomic nitrogen and nitric oxide concentrations, and the ion-atom interchange and dissociative recombination rate coefficients. The "best fit" results for both sets of profiles are achieved with the rate coefficients ($cm^3\ sec^{-1}$) at 300°K given by $Y_{N_2} = 1.1 \times 10^{-12}$, $Y_{O_2} = 2.0 \times 10^{-11}$, $\alpha NO^+ = 3.5 \times 10^{-7}$, and $\alpha O_2^+ = 3.1 \times 10^{-7}$ with an assumed inverse temperature dependence of all the rate coefficients and for an assumed Jachhia model atmosphere. In addition, the "sunset" best fit solutions require that the minor neutral concentrations at 200 km be $[N] = 1 \times 10^7\ cm^{-3}$ and $[NO] = 3 \times 10^5\ cm^{-3}$ and that the net vertical plasma transport, $W_z$, due to $\overline{E} \times \overline{B}$ drift and a neutral wind be downward with a speed of 9 m $sec^{-1}$. The midnight best fit solutions are achieved with $[N(200\ km)] = 2 \times 10^6 cm^{-3}$, $[NO(200\ km)] = 6 \times 10^4\ cm^{-3}$, and $W_z = 10$ m $sec^{-1}$ upward.

The 6300 Å nightglow morphology in the inter-tropical region is computed directly from the ion concentrations calculated for assumed drift and neutral wind models representative of equinoctal, sunspot minimum conditions. Isophote contours of zenith intensity are presented to illustrate the nightglow morphology associated with the decay of the Appleton anomaly. Calculated results are compared with the observations of Barbier to demonstrate the influence of electrodynamic drift perturbations on the morphology of nightglow enhancements. The results show that the electrodynamic drifts required to produce the observed enhancements are consistent with the drifts observed at Jicamarca.

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Brasher, W. E., and W. B. Hanson, "Distributions of Nighttime F-region Molecular Ion Concentrations and 6300 Å Nightglow Morphology," Radio Science, 5(11), 1325, 1970.

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Holmes, J. C., C. Y. Johnson and J. M. Young, "Ionospheric Chemistry," Space Research V (COSPAR), edited by P. Muller, North Holland Publishing Company, 756, 1965.

Sterling, D. L., W. B. Hanson, R. J. Moffett and R. G. Baxter, "Influence of Electromagnetic Drifts and Neutral Air Winds on Some Features of the $F_2$ Region," Radio Science, 4(11), 1005, 1969.

(c) Tropical ultraviolet nightglow

Recently, Knudsen (1970) suggested that the recombination of positive and negative atomic oxygen ions might explain the tropical ultraviolet nightglow observed in OGO 4. This suggestion has been initially examined and quantitatively compared (Hanson, 1970) with the previous suggestion by Hanson (1969) that the nightglow arises from radiative recombination of $O^+$ ions. It was demonstrated that unless our knowledge of the appropriate rate coefficients is seriously in error the ion-ion recombination scheme must play a subsidiary role as a source of this radiation. At this time it is not clear whether either mechanism is adequate to produce the observed radiation intensity, though both must surely contribute.

Dr. Tinsley is in Brazil at the time of this writing to make ground observations of visible radiations to be expected from the different mechanisms to provide further constraints on the hypothesis.

References

Hanson, W. B., "A Comparison of the Oxygen Ion-Ion Neutralization and Radiative Recombination Mechanisms for Producing the Ultraviolet Nightglow," J. Geophys. Res., 75, 4343, 1970.

Hanson, W. B., "Radiative Recombination of Atomic Oxygen Ions in the Nighttime F Region," J. Geophys. Res., 74, 3720, 1969.

Knudsen, W. C., "Tropical Ultraviolet Nightglow from Oxygen Ion-Ion Neutralization," J. Geophys. Res., 19, 1970.

(d) Meteoric ions in the F2 region

The ion trap on OGO 6 has revealed the presence of ions of mass 56 $\pm$ 2 AMU at altitudes above 400 km (Hanson and Sanatani, 1970). These authors suggested that the ions were $Fe^+$ and were probably transported to great heights by the upward $\overline{E} \times \overline{B}$ drift near the equator in the daytime.

We have now carried out quantitative calculations that show in detail how this dynamical process would behave, given an arbitrary source of $Fe^+$ ions at 150 km. Different source intensity and distributions were adopted and the calculations were carried out for different electric fields, all in the range of observation, and for different ion masses since silicon ions might also be expected to be present. The following conclusions were reached. (The results were presented at the 1970 Boulder Electric Fields Conference.)

1) The phenomenon is principally an equatorial one.

2) The distribution of the meteoric ions is relatively insensitive to the source configuration.

3) Observed vertical ionization drifts at the equator are quite adequate to carry the meteoric ions to altitudes well above 400 km.

4) There is a tendency for the ions to diffuse down field lines away from the equator, but probably not to latitudes much greater than 15 degrees.

A statistical analysis of more OGO trap data is now being made which reveals that the effect is indeed confined to the near equatorial region. This analysis will be pursued to see what can be inferred about the dependence on magnetic activity and whether any clues as to the physical source of the meteoric ions can be obtained.

<u>Reference</u>

Hanson, W. B. and S. Sanatani, "Meteoric Ions Above the $F_2$ Peak," J. Geophys. Res., 75 (28), 5503, 1970.

(e) Minor ion distributions at the magnetic equator

A Javelin rocket was used to measure the ion distribution above the magnetic equator at Natal, Brazil, in June 1969. Because of the suppression of vertical plasma diffusion at the equator, the ion distributions are determined primarily by photochemistry and $\overline{E} \times \overline{B}$ drifts. These data are being analyzed and a companion effort of interpreting the data by treating the photochemistry in the $\overline{E} \times \overline{B}$ drift frame of reference is being pursued with the help of R. J. Moffett.

Good agreement between the total ion concentration obtained from an ion trap and from the mass spectrometer can only be obtained by making appropriate rocket velocity corrections to the mass spectrometer collection efficiency.

The observed ambient ions included $H^+$, $D^+$, $He^+$, $O^{++}$, $N^+$, $O^+$, $N_2^+$, $N_O^+$, and $O_2^+$. In addition, the ion $H_2^+$ was observed near 200 km but it is not now known whether this was a contaminant ion. Because of the poor vacuum pumping facilities available at the base, many more contaminant ions were observed than usual.

Only the ions $H^+$, $He^+$, $O^{++}$, $N^+$, and $O^+$ are presently being included in the calculations, but the molecular ions will be treated eventually after modifications in the program are made. Quite reasonable fits for the $H^+$, $He^+$, and $O^+$ ions are readily obtained with customary parameters, but $N^+$ and $O^{++}$ appear to require unorthodox processes on cross-sections to fit the observations. This work is still in progress.

D. L. Sterling
W. B. Hanson
R. J. Moffett

(f) Equatorial F-region morphology

The time-varying continuity equation for electrons is solved for the F-region of the ionosphere at low latitudes. The continuity equation includes all the pertinent F-region processes, such as electrodynamic drift, neutral wind interaction, photo-ionization, ambipolar diffusion, and recombination.

The technique of solution is discussed in Sterling et al., 1969. Present work involves the use in the model of actual $\underline{E} \times \underline{B}$ drift measurements at Jicamarca, Peru. Better agreement between the model and observations is expected.

Reference

Sterling, D. L., W. B. Hanson, R. J. Moffett, and R. G. Baxter, "Influence of Electromagnetic Drifts and Neutral Air Winds on Some Features of the $F_2$ Region," Radio Science, 4 (11), 1005, 1969.

D. L. Sterling
W. B. Hanson

(g) Equatorial F-region solar eclipse

The effects of a total solar eclipse on the equatorial F2-layer for sunspot minimum conditions have been studied by obtaining transient solutions of the time-varying continuity equation. The published results (Sterling and Hanson, 1970) show that the equatorial eclipse F1.5 layer (on ionograms it appears as a cusp between $f_oF1$ and $f_oF2$) can be explained in terms of electrodynamic drift. This layer is very prominent at the magnetic equator during a solar eclipse, and it has been attributed by others to the increased recovery time of the ionosphere with height. The technique used by ionospheric workers for deducing the daytime electron production rate q and the loss coefficient $\beta$ from equatorial eclipse data was evaluated. It was found that the deduced values of $\beta$ could be seriously in error if vertical drift is not included in the calculations.

Present work involves extending the calculations to sunspot maximum conditions. Measurements of vertical drift at Jicamarca during the 11 September 1969 solar eclipse are being used. The model concentrations are being compared with the observed concentrations. Also, comparisons will be made with the Danger Island eclipse of 12 October 1958. A better understanding of the importance of transport of ionization versus photochemical changes is expected.

Reference

Sterling, D. L. and W. B. Hanson, "Calculations for an Equatorial F2-Region Solar Eclipse," Radio Science, 5 (7), 1029, 1970.

4. Atmospheric Chemistry and Reaction Kinetics

C. B. Collins
M. J. Shaw

The Atmospheric Chemistry Group has been engaged in a continuing program to gain an increased knowledge of the mechanisms effective in ion-electron recombination in order to make possible the confident extrapolation of laboratory measurements to extra-laboratory environments. Work during the past year has centered around the successful development of a model-independent technique for the measurement of the rate coefficient for three-body ion-electron recombination.

Helium was chosen as a vehicle for this research, because it is a relatively simple inert gas and more experimental data on afterglow processes is available for it than any other gas. The experiment is being conducted in the UT Dallas pulsed afterglow system described in the literature (Collins and Hurt, 1968). The parameters being measured are the lifetimes of the electron, $He^+$ and $He_2^+$ densities, and the radiation from the excited states of He and $He_2$ resulting from recombination. These quantities are measured with a microwave interferometer, differentially pumped mass spectrometer, and tandem monochromator, respectively. The data from these instruments is analyzed with a highly sophisticated data acquisition system (Collins and Hurt, 1969), the core of which is an on-line, programmable computer. This data acquisition system enables weak signal recovery far in excess of that available in previous afterglow studies.

Recombination rates are being determined by analyzing the absolute intensity of radiation from appropriate series of excited levels of neutral helium to determine the net rate at which neutral helium is being produced at a given time in the afterglow cycle. This rate divided by the product of the measured electron and helium atomic ion densities at the same afterglow time yields the recombination coefficient for a particular value of electron density. Since each of these quantities is being measured throughout the afterglow, the recombination coefficient of helium atomic ions can be determined as a function of electron density. This procedure is feasible primarily because radiative de-excitation dominates sufficiently over collisional de-excitation for the lower excited levels of neutral helium. Indeed, an estimate of the error of the experimental recombination coefficients can be made by comparing the calculated collisional and radiative de-excitation rates out of these lower levels. Careful analysis of the contribution of the resonance $^1P$ levels to the net recombination rate will be made by applying the theoretical treatment of Holstein (1947) on trapped radiation to the appropriate afterglow cell geometry.

This procedure for determining recombination coefficients has the distinct advantage over other methods (Born, 1968) in that it does not require the loss of charged particles to be dominated by recombination. In any afterglow experiment there will be processes such as diffusion and electron detachment that compete with recombination in determining the net loss rate of ions and electrons in the afterglow. In helium, attachment processes are negligible and the effect of diffusion can be reduced by increasing the afterglow cell dimensions. However, diffusion will always become important at sufficiently late times and in the case of helium there are important <u>sources</u> of ions and electrons in the afterglow as a result of reactions between pairs of metastable atoms and metastable molecules (Collins and Hurt, 1969). The recombination coefficients obtained from the net radiation losses of selected atomic levels are not affected by the presence of any production or competing loss mechanisms of ions and electrons.

To date definitive measurements of the recombination rate coefficient for $He^+$ and $He_2^+$ have been made for a neutral gas pressure of 44.6 Torr. These results, recently published (Collins, Hicks, and Wells) and presented in Figure 1 represent the only direct measurements of instantaneous, spatially localized values of recombination rate coefficient. In this figure, measurements are shown as rectangles

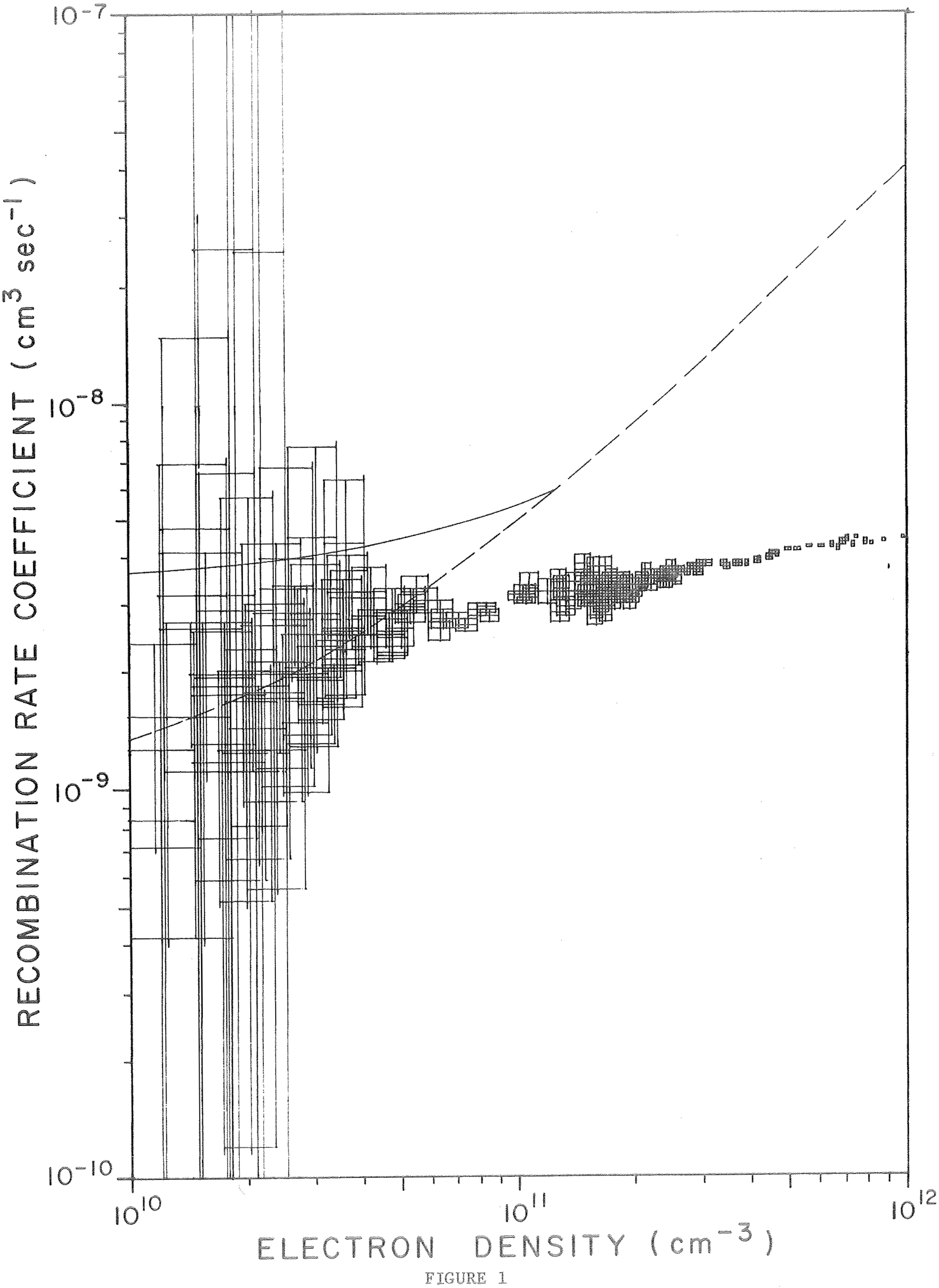


FIGURE 1

Fig. 1 Graph of rate coefficients for the recombination of $He_2^+$ ions with electrons as a continuous function of electron density at a neutral helium pressure of 44.6 Torr. The scaled values resulting from this work are shown as rectangles bounded by the accumulated statistical errors of measurement and including the average values within each. For comparison the results interpolated for the same neutral gas pressure from the measurements of the Saclay group (Ref. 7) are plotted without statistical error (solid curve), together with the predictions of theory (dashed curve).

bounded by the accumulated statistical errors of measurement and include the average value within each. For comparison, the results interpolated from the model-dependent measurements of the SACLAY group are plotted (solid curve) together with the predictions of theory (dashed curve).

Considerable disagreement with theory can be seen and indications are that collisions of the ion-electron system with neutral particles provide a much stronger stabilizing effect than anticipated by theory.

Measurements in progress at 1.6 Torr should contribute materially to our understanding of the processes. Ultimately the rate of recombination will be measured over a range of pressure, but since each requires of the order of $10^9$ discrete, digital measurements, progress is necessarily slow.

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5. Numerical Mathematical Techniques

T. N. L. Patterson

Work on numerical quadrature has focussed principally on the theory underlying the new integration rules which have recently been developed (Patterson, 1968). Of greatest concern is the question of the general existence of the rules for various types of weight functions. A summary of the present state of knowledge on rule extension is

(1) Gauss, Lobatto and Gauss-Jacobi formulae with weight function $(1-x^2)^\lambda$ , $\lambda > -1/2$ can always be extended once.

(2) Gauss Lagnerre 2 point formula cannot be extended.

(3) Gauss Hermite 2 point formula can be extended only once.

(4) Gauss 2 point formula can be extended four times only.

(5) Gauss 3 point formula can be extended at least six times.

(6) Gauss 4 and 5 point formulae can be extended at least five times.

With the exception of (1) which is an analytical result, all results are experimental. For further progress in developing new rules the computational schemes will need considerable refinement.

Some consideration has also been given to the techniques of numerical experimentation. The work is based on the premise that numerical analysis is inferential rather than deductive in nature, but that there is a general reluctance to accept this premise. The situation is typified by deductive methods of error analysis based on mathematical analysis which generally produce results too crude to be of practical value. It is believed that the theoretical criteria underlying new methods need careful experimental assessment. In an attempt to indicate how such an assessment should be carried out, detailed consideration is being given to the basis of certain optimum quadrature rules which have been developed (Bamhill and Wixom, 1967) to integrate functions which have a defined region of analyticity. Preliminary results show that the theoretical basis is ill-founded. A paper on this topic is being prepared for an international meeting next year.

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6. Balloon Program

R. P. Bukata

Albedo particle fluxes at balloon altitudes

A program to study the directional dependence of the secondary cosmic radiation near the top of the atmosphere is currently being executed. The study is progressing along both theoretical and experimental avenues. The complex motions of charged particles within the terrestrial magnetic field are being traced via computer programs which simulate the trajectories of the ionic component of the cosmic radiation through mathematical approximations of the magnetic field, particular attention being given to the behavior of the "re-entrant" and "splash" albedo particles. Initial results of such computer programming appear to verify the expected "bounce" motion of such particles between conjugate magnetic mirror points. However, such motion is not a singular solution to the problem. Other solutions to the problem include points between the conjugates including loop motions back to the point of particle creation. In order to supplement the theoretical investigation of albedo particle motion with direct experimental observations of the directional distribution, a balloon package was launched from Palestine, Texas, on November 7, 1969. The package was intended to study the zenith-azimuth propagation and charge composition of the albedo radiation in the energy range 10-200 Mev/nucleon.

Although some of the acquired data must be regarded as suspect (due to periodic malfunctions of the power supply system) attempts are currently being made to extract the useful data. A second aim of the balloon package, which was considerably more successful, was a feasibility test of the package (a $\frac{dE}{dx}$ - E telescope with an onboard computer particle discriminating translational network) for possible inclusion in future satellite missions.

## 7. Seismology

A. Dziewonski

(a) Study of upper mantle by long period surface wave dispersion

This program consists of measurements of dispersion parameters of mantle waves as well as of the subsequent inversion of these data.

The techniques of the analyses of surface wave dispersion developed at The University of Texas at Dallas (cf. Landisman, Dziewonski and Sato, 1969; Dziewonski and Landisman, 1970) are used in measurements of mantle Rayleigh and Love waves travelling around the world on multiple paths. A study "On regional differences in dispersion of mantle Rayleigh waves" has been presented by Dziewonski (in press). These data in conjunction with data published by other authors have been recently inverted in a paper by Dziewonski, "Upper mantle models from 'pure' path data." Significant differences have been found between average oceanic, shield and tectonic region structures. Oceanic models are characterized by a well developed low velocity zone. For the set of data used on this study the thickness of the oceanic lithosphere proves to be a critical parameter which influences the density solutions. If the thickness of the lithosphere is 80 km or less, a reversal of density distribution is necessary to explain the data. If the thickness is 100 km or greater, the densities between 10 and 400 km can be represented by a simple average value.

The shield data do not require a low velocity channel where the velocity in the lid is 4.60 km/sec or less but do require one for higher $S_n$ velocities.

The characteristic feature of models for tectonic areas is high shear velocity (>4.80 km/sec) between 200 and 400 km. It could be explained by the thrust of oceanic lithosphere under tectonic regions (Press, 1971).

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A. L. Hales

(b) Regional variations in upper mantle properties

Earlier studies of the travel times of P waves have shown that there are regional variations in these travel times. The arrivals are systematically late in tectonically active regions such as the Western United States or the Carpathians, and systematically early in shield or platform areas such as the central United States. Although the relative values in any one continent found by different investigators were consistent, there were some differences in intercontinental comparisons. This arose partly because of the azimuthal variation of the P station anomalies. The phase PKIKP traverses the upper mantle at steep angles. Thus, it would be expected that PKIKP station anomalies would exhibit less azimuthal error. They would also be less affected by small errors in the location of the earthquakes.

A preliminary investigation (Cleary and Hales, 1970) confirmed this expectation and suggested that there were errors in the travel times. A study similar to that of P travel times was undertaken. A paper describing the study is being prepared for publication.

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M. Landisman

(c) Observations and seismological theory in studies of the crust and mantle; resolving power of geophysical measurements

A cooperative program in seismology between scientists in the Geosciences Division of The University of Texas at Dallas and Professor Y. Satô and his colleagues in the Earthquake Research Institute of the University of Tokyo led to a major invited paper, "Contributions of Theoretical Seismograms to the Study of Modes, Rays and the Earth," by

M. Landisman, T. Usami, Y. Satô and R. Massé, which was published in the August, 1970 Reviews of Geophysics. This study points the way toward improved understanding of the relation between the interior of the Earth and the seismograms recorded on its surface, and its implications are being pursued.

A similar cooperative program between workers in this institution and Professor S. Mueller and his colleagues in the Geophysical Institute of the University of Karlsruhe in West Germany has produced a number of studies of the crust and upper mantle. These investigations have explored the possibility that minima in the velocity-depth function may exist for several areas that have been studied in detail, including sites in the southern Great Plains and the Basin and Range of North America, the Rhine rift system in western Europe, and southern Africa. Attempts were also made to relate these proposed low-velocity regions to other properties at depth. Correlations with an inferred zone of low electrical resistivity and a region of increased seismic attenuation suggest the possibility that extremely minor concentrations of interstitial free water of hydration may be an important agent in a number of processes that act within the Earth at moderately shallow depths.

Two students, R. Massé and Z. A. Der, were supported in their doctoral research by the NASA grant. Mr. Massé is studying the upper mantle beneath the Western United States, using LRSM and other seismological data including amplitudes as well as arrival times. He also participated in a study, "Effects of Observational Errors on the

Resolution of Surface Waves at Intermediate Distances," by Z. Der, R. Massé, and M. Landisman, which appeared in the Journal of Geophysical Research, Volume 75, pages 3399-3409, 1970. This research is now being pursued by Z. Der and M. Landisman in an attempt to consider the effects of additional unknown parameters and further observations.

8. Petrology-Geochemistry

J. L. Carter

(a) Electron microprobe analysis of ultramafic and mafic nodules from Kilbourne Hole, New Mexico, and Potrillo, New Mexico

As part of the continuing study of the chemical nature of the Earth's upper mantle, coexisting phases from both 3-phase and 4-phase nodules from Kilbourne Hole, New Mexico, were reported in the December 1969 annual report.

One interesting finding was the apparent presence of coexisting spinels of different compositions in some of the 4-phase nodules. This observation led to the speculation of an extensive solvus between certain spinel compositions. Preliminary probe data on the coexisting silicate phases from the nodules that contain two spinels suggest that the silicate phases may also be chemically heterogeneous.

Preliminary analysis of coexisting phases from both 3-phase and 4-phase nodules from Potrillo, New Mexico, give similar results. Nodules from both Kilbourne Hole, New Mexico, and Potrillo, New Mexico, have been found that have angular fragments of 4-phase nodules in a 3-phase nodule matrix. These data suggest a rather complex history for their formation including partial fusion, partial crystallization, recrystallization, and metasomatic processes. Polished thin sections will be analyzed to facilitate a more critical interpretation of these samples and thus the processes responsible for their formation.

W. I. Manton

(b) Lebombo rhyolites

Pursuing the hypothesis that the Lebombo rhyolites originated by the partial fusion of sediment, Manton has carried out chemical analyses of the rhyolites used in his Rb-Sr investigation. The rocks show little variation in composition and have an average composition that is granodioritic (Table 1).

The reason for carrying out these analyses was to examine what similarities exist between the Lebombo rhyolites and the Taupo rhyolites of New Zealand, for which an origin by the melting of sediment appears likely (Ewart and Stipp, 1968). The most striking geochemical feature of the Taupo rhyolites is their trace and major element composition (Taylor et al., 1968) which appears incompatible with an origin involving fractional crystallization. No such incompatibility can be demonstrated for the Lebombo rhyolites for the reason that their bulk composition is granodioritic and would not naturally be accompanied by any enrichment of trace elements. If, however, the rocks originated by partial fusion they should show no or very minor modification by fractional crystallization. A suitable means of examining the influence of fractional crystallization is to plot K/Rb against Rb/Sr (Figure 2). Both these parameters are sensitive indicators of the crystallization of felspar.

K/Rb will decrease largely as the result of the crystallization of K-felspar; Rb/Sr will increase with the crystallization of plagioclase. Eight granites from the Dembe-Divula and Masukwe complexes which cut the volcanics in the Nuanetsi district are also plotted in Figure 2. The granites whose initial $Sr^{87}/Sr^{86}$ ratios are indistinguishable from the volcanics (Manton, 1968) may be considered as differentiates from a magma similar in composition to the ignimbrite magma. Figure 2 implies that the Lebombo rhyolites were not greatly modified by fractional crystallization.

Uranium analyses have been performed by isotope dilution on some of the Lebombo rhyolites and on the Masukwe and Dembe-Divula granites. In the rhyolites the K/U ratio is very close to $1 \times 10^4$, but in the more fractionated granites falls as low as $0.32 \times 10^4$. These data may be taken as further evidence of the lack of fractional crystallization within the main body of the rhyolites.

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W. I. Manton

(c) Lead isotope studies

Compston and Oversby's (1969) technique of mass fractionation correction in the isotopic analysis of lead has been somewhat modified for use in this laboratory.

The isotope dilution equation may be written as:

$$\frac{\text{moles of i'th isotope in mixture from spike}}{\text{moles of i'th isotope in mixture from rock}} = \frac{r-m}{m-s} = R \qquad (1)$$

where r is the abundance ratio of the (i+n)th to the i'th isotope in the rock, and m and s are similarly defined for the mixture and the spike.

In practice absolute value of s may be obtained by calibrating the spike against an absolute standard, but m and r as measured are subject to mass fractionation. We can write

$$m = m' \, (1 + nf_m)$$

$$\text{and} \qquad (2)$$

$$r = r' \, (1 + nf_r)$$

where m' and r' are the ratios measured on the mass spectrometer and $f_m$ and $f_r$ are the fractionations per unit mass incurred in the analyses of the mixture and the rock. Substituting these expressions for m and r in the original equation and simplifying, we get,

$$R(m'-s) + nm' \; (1 + R)f_m - nr'f_r + r'-m' \tag{3}$$

For lead, three independent equations in the form of (3) may be written in terms of the unknowns R, (1 + R) $f_m$ and $f_r$. A program has been written in APL to solve them.

Compston and Oversby's original double-spike required mixtures in which $Pb^{207}$ had four times the abundance of $Pb^{206}$. Resolution between the $Pb^{207}$ and $Pb^{206}$ peaks was severaly impaired and they reported mass 207 tails 1%-2% of the height of the 206 peak. Such a situation is obviously undesirable. For the purposes of mass spectrometry, the best mixture would be one in which $Pb^{204} = Pb^{206}$ and $Pb^{207} = Pb^{208}$, with composition of common Pb naturally causing the $Pb^{208}$ and $Pb^{207}$ peaks to be twice the height of $Pb^{204}$ and $Pb^{206}$. We have examined the error propagation in such a mixture made of the NBS standard, SRM 981 (common Pb), and a spike made of the most highly enriched $Pb^{204}$ and $Pb^{207}$ available from Oak Ridge, with the composition $Pb^{204} = 0.4749$; $Pb^{206} = 0.00082$; $Pb^{207} = 0.5236$; $Pb^{208} = 0.00062$.

We used the method of Compston and Oversby and raised by 1% the ratios measured in the analysis of the rock and the mixture. The results are given in Table 2 and should be compared with Table 7 of Compston and Oversby. In five cases (blocked off in Table 2) our error magnification slightly exceeds theirs. In the remaining fifteen, ours is less than theirs.

<u>Reference</u>

Compston, W. and V. M. Oversby, "Lead isotope analysis using a double spike," <u>J. Geophys. Res.</u>, <u>74</u>, 4338, 1969.

Table 1. Average composition of Lebombo rhyolites (32 analyses).

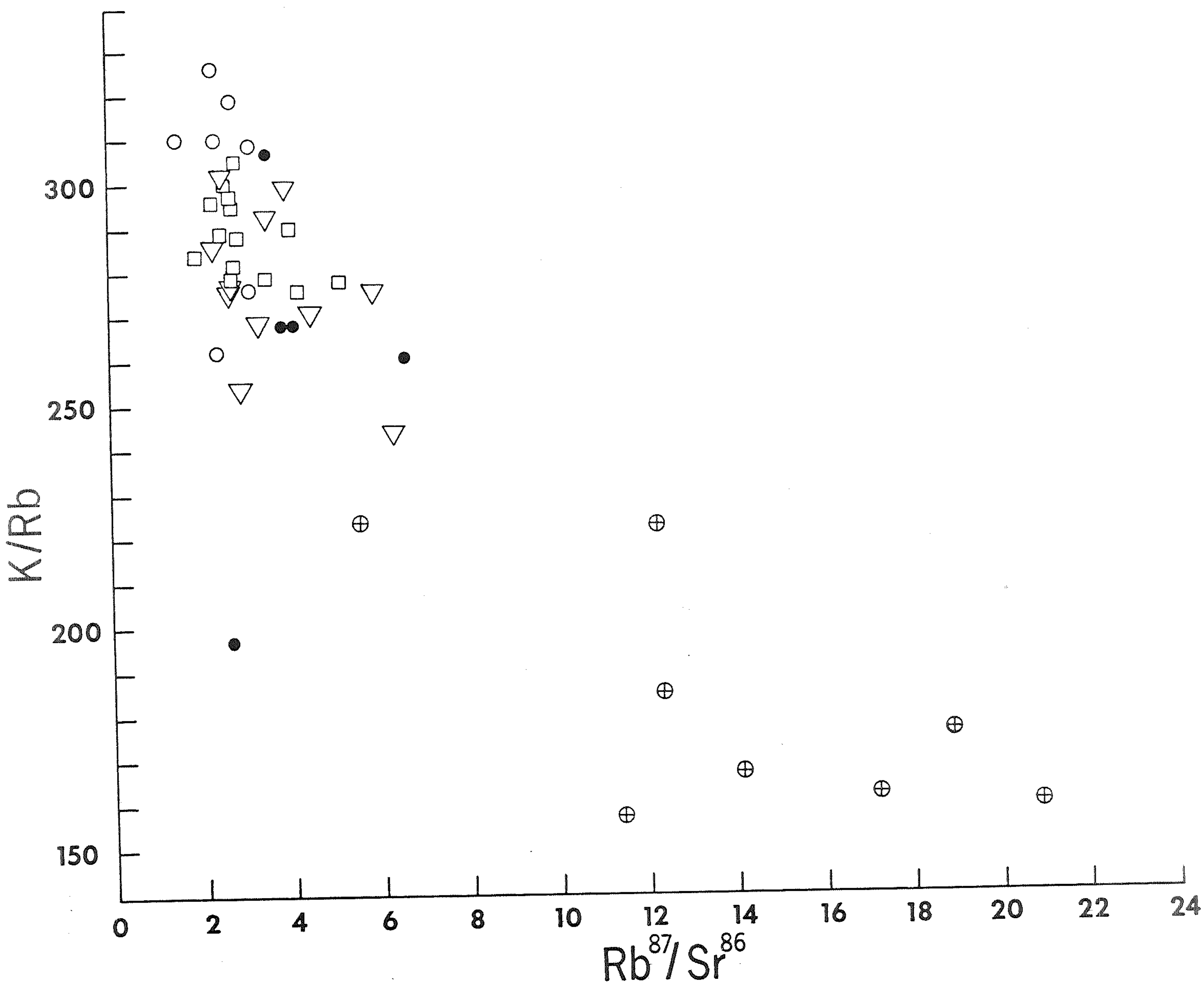
| | |
|---|---|
| $SiO_2$ | <71.54 |
| $Al_2O_3$ | 11.70 |
| $Fe_2O_3$ | 6.03 |
| $MgO$ | 0.40 |
| $CaO$ | 2.20 |
| $Na_2O$ | 3.23 |
| $K_2O$ | 4.42 |
| $TiO_2$ | 0.48 |

Silica determined by difference and represents a maximum figure.

Table 2. SRM981 Error Propagation Test

| | 208/ 206 | Error on % | 207/ 204 | Error on % | 206/ 204 | Error on % |
|---|---|---|---|---|---|---|
| Correct Values | 2.16805 | | 15.490 | | 16.9365 | |
| Composition ratios raised one at a time | | | | | | |
| 208/206 up 1% | | +0.273 | | +1.88 | | +1.25 |
| 207/206 up 1% | | -0.48 | | -1.74 | | -0.49 |
| 206/204 up 1% | | -0.03 | | -1.05 | | -1.03 |
| Mixture ratios raised one at a time | | | | | | |
| 208/206 up 1% | | -1.28 | | -1.96 | | -1.31 |
| 207/206 up 1% | | +0.53 | | +0.79 | | +0.53 |
| 206/204 up 1% | | +0.70 | | +1.04 | | +0.70 |

Figure 2. Plot of K/Rb vs $Rb^{87}/Sr^{86}$ for Lebombo and Nuanetsi lavas and Dembe-Divula and Masukwe granites. Open circle - Lower Lebombo rhyolites. Square - Middle Lebombo rhyolites. Triangle - Upper Lebombo rhyolites. Closed circle - Nuanetsi rhyolites. Cross in circle - Dembe-Divula and Masukwe granites.



D. C. Presnall

(d) Interpretation of chemical variations in the rocks of the Sierra Nevada batholith

A joint project with P. C. Bateman of the U. S. Geological Survey has been undertaken in an effort to better understand the chemistry of the granitic rocks of the central Sierra Nevada batholith. About 150 chemical analyses of the granitic rocks consist of 80% or more normative quartz + orthoclase + albite + anorthite. This four-component system is sufficiently well known that the chemistry of the rocks can be compared directly with the phase diagram in a fairly detailed way.

A combination of evidence from field relationships, chemical data on the rocks, and the phase diagram yields the following general conclusions:

The granitic rocks cannot be crystallized from pure melts. Rather, the plutons were most likely intruded as crystal-liquid mushes containing a large proportion of plagioclase phenocrysts. The source region is believed to lie at the base of the crust. After partial melting of a mixture of lower crust and upper mantle took place, the entire partially melted mass moved upward and crystallized higher in the crust. Chemical variations between plutons can be explained as partly due to different chemistry in the source regions and partly due to subtraction of plagioclase.

This work is now being prepared for publication.

9. Study of the Conductivity of the Crust and Upper Mantle with an Array of Variometers

H. Porath
A. Dziewonski

The University of Texas at Dallas, together with the University of Alberta at Edmonton, has been engaged since 1967 in a program designed to investigate lateral changes in the conductivity of the upper mantle beneath the western United States (Reitzel, Gough, Porath and Anderson, 1970; Porath, Oldenburg and Gough, 1970; Camfield, Gough and Porath, in press). The results of these studies have been summarized by Porath and Gough (in press).

The University of Texas at Dallas also began in 1969 a program of localization of geomagnetic variation anomalies associated with the geological formations in the upper crust. Studies of this kind have been carried out in North Texas and Oklahoma and Midwestern United States (Porath and Dziewonski, in press). Continuation of this direction of investigation should be helpful in determination of the regions in which the classical magnetotelluric method cannot be applied and/or caution should be exercised in interpretation of the results.

This study is supported in part by the National Science Foundation.

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10. Magnetic Properties of Earth and Lunar Materials

C. E. Helsley

The successful return of lunar material from the Apollo 11 and 12 missions has focused our efforts on the analysis of magnetic properties of rocks of earth as well as lunar origin. Initial studies on the Apollo 11 and 12 materials show that the samples are magnetic with iron, ilmenite, and perhaps troilite, being the major magnetic constituents. The magnetism is stable and is interpreted as being of lunar origin either from a field internal to the moon or as the result of the moon being within the earth's magnetic field at the time the rocks cooled ($4.0 \pm$ billion years ago).

Continued studies of the magnetic properties of red sediments have established a correlation framework, based on magnetic reversals for the Moenkopi formation of the Colorado Plateau. Studies on the Permian Cutler Formation have shown that no reversals are present throughout a time span of more than 20 million years, once again supporting the world-wide observation of a long period of constant polarity for the late Pennsylvania and most of the Permian. Moreover, studies of the stability of these rocks and those from the Moenkopi Formation suggest that most of the unstable moment is acquired through weathering processes and resides in the mineral goethite. This unstable moment can generally be removed by judicious heating of the sample.

Paleomagnetic studies on Precambrian rock made by H. R. Spall for his Ph. D. dissertation at the University of London in 1970 have been completed and provide evidence for an extensive period of polar wandering in the late Precambrian (2700 to 1000 m.y. ago). This work is currently being submitted to various journals for publication.

11. Calcification: Amino Acid Composition of Protein in $CaCO_3$ from Some Invertebrates and Algae

R. M. Mitterer

Calcium carbonate, as aragonite or calcite, is a major structural feature in some representatives of many invertebrate phyla including such diverse groups as mollusks, corals, worms and echinoids, and in calcareous algae. In common with other mineralized tissues in biological systems, these hard parts have an organic matrix composed principally of a protein-polysaccharide complex. While the exact mechanism is not known, calcification in these organisms is thought to be induced by the mucoprotein matrix which provides nucleating sites for $CaCO_3$ precipitation. Amino acid analyses may provide some insight into calcification mechanisms by showing whether the proteins in various calcified structures have something in common.

Amino acid analyses of mineralized protein have been obtained for several different genera of corals, red and green algae, foraminifera, mollusks, and worms. The composition of the organic matrices is remarkably similar for most of the samples, considering the diverse nature of the organisms and of the calcified structures. All of the samples are characterized by a high content, at least 35% of the protein, of the acidic amino acids aspartic and glutamic acid. The basic amino acids, lysine, histidine, and arginine, are low, comprising about 5-10%. It has been suggested that the acidic amino acids in the protein of mineralized tissues is important in concentrating calcium ions because of their polar side groups. The data obtained in the present study from a variety of invertebrate mineralized tissues and calcareous algae suggests that a protein rich in the acidic amino acids may be intimately involved in invertebrate calcification.

12. Relativity

M. Cahen
I. Ozsvath
W. Rindler
I. Robinson

The interaction between mathematics and relativity has always been lively in both directions. Highly abstract results of Palais and Ebin seem now to have found applications in the theory of relativistic superspace. We therefore believe that the study of hyperbolic differential geometry per se can have a double justification. We have found that the group of transvection of an indecomposable Lorentz symmetric space is either solvable or semi-simple; if solvable, then it is an abelian extension of the Heisenberg group (M. Cahen and N. Wallach, Bull. Am. Math. Soc. 76, 1970, 3). First extensions of these results to other pseudo-Riemannian symmetric spaces have been obtained, and the strength of the hyperbolic condition has become evident (M. Cahen and M. Parker, Bull. Soc. Belge Math., in press). An exhaustive list of four-dimensional symmetric spaces has been constructed (to be published) and work on the 5, 6, and 7-dimensional cases is in progress.

We have also obtained a compact form of the Green function for Dirac equations in terms of hypergeometric functions (to be published).

Work has continued on empty-space solutions without symmetry of Einstein's equations and on a new approach to the motion of singularities (I. Robinson, Lectures on Motion and Radiation in General Relativity, Collège De France, 1970).

Our earlier work in cosmology had shown that there are four different classes of fully homogeneous dust-filled universes (I. Ozsváth, J. Math. Phys. 6, 1965, 590; D. L. Farnsworth and R. P. Kerr., J. Math. Phys. 7, 1966, 1625). In our program of summarizing the geometrical and physical properties of these universes, two papers have already been published (I. Ozsváth and E. L. Schücking, Ann. Phys. 55, 1969, 166; I. Ozsváth, J. Math. Phys. 11, 1970, 2871). Work on the third and last paper in this series is now in progress.

Recently we have developed new methods for dealing with spatially homogeneous world-models. (I. Ozsváth, J. Math. Phys. 11, 1970, 2860). We proposed a Lagrangian formulation of Einstein's field equations with incoherent matter applicable to such models. This formulation is powerful enough to reduce the solution of the field equations (under certain slight restrictions on the motion of the matter) to the solution of a problem analogous to those dealt with in classical mechanics. We have regularized that mechanical problem for a class of special solutions. Furthermore, we give the reduction of the mechanical problem in the "symmetric" case of Gödel.

In a forthcoming paper on spatially homogeneous rotating universes we show that there are "symmetric" cases for all the Class I groups, and we give the reduction of the corresponding mechanical problems to three degrees of freedom.

It is a consequence of the interaction between the gravitational and electromagnetic fields in general relativity theory that gravitational induction effects not merely modify known classical solutions of the

Maxwell equations, but also create entirely new ones. Thus, for example, by heuristic use of Mach's principle it can be conjectured (Rindler, Essential Relativity, 1969) that a stationary charged sphere inside a rotating mass shell will be surrounded by a magnetic dipole field. This conjecture was examined, and found to be essentially correct (J. Ehlers and W. Rindler, Physics Letters 32A, 1970, 257; see also New Scientist, 8 Oct. 1960, p. 64). We learned later that a similar problem had been considered by J. M. Cohen (Phys. Rev. 148, 1966, 1264), but our method complements his; whereas he need not restrict the outer shell mass, his Maxwell field is a mere test field, and he can work to first order in the rotation speed only. Our outer mass is restricted, but our equations are fully coupled and we can work to second order in the rotation speed. We thus get an induced electrostatic field, even inside the inner shell (to be published), which is beyond Cohen's method. We have also suggested experiments which could test these effects, at least in principle. In the case of fast-rotating neutron stars, these effects might be significant.

In 1960 we proposed (W. Rindler, Phys. Rev., 119, 1960, 2082) a definition of motion with constant proper acceleration ("hyperbolic motion") in curved spacetime by generalizing the geometric properties of such motion in flat spacetime. The definition required of the world line that it be torsion-free and of constant curvature. In 1969 R. Gautreau (Phys. Rev. 185, 1969, 1662) gave a new interpretation of this definition as a motion with constant three-acceleration vector relative to the local (Fermi-transported) Minkowski rest frame. We have now proved (L. Karlov and W. Rindler, to appear in Phys. Rev.) that any torsion-free motion corresponds to a three-acceleration which has fixed direction in the local frame. We are in the course of finding similar kinematic characterizations of the other basic geometric invariants of twisting world lines.

A historical study was made (Rindler, Am. J. Phys. 38, 1970, 1111) concerning the question of who had first recognized that the relativistic time dilation is a physical phenomenon rather than a mere mathematical device. Whittaker and other historians had attributed this variously to Lorentz or Larmor. We have found, however, that the credit belongs unequivocally to Einstein.

## III.

## Other Space Related Research

### 1. Lunar Atmosphere

F. S. Johnson
J. H. Hoffman
D. E. Evans (Manned Spacecraft Center, Houston, Texas)

A cold cathode vacuum gauge has been included in the Apollo Lunar Surface Experimental Package (ALSEP) to measure ambient lunar atmosphere and gaseous contamination of the landing site. The gauge has the capability of operating down to a pressure of about $10^{-12}$ torr.

The most interesting prospect is that gases of internal lunar origin are present, in which case their composition will be of geochemical interest. The cold cathode gauge cannot determine composition, and Dr. Hoffman is building a mass spectrometer that should be valuable in this connection. The mass spectrometer should make significant measurements even in the presence of contamination, so long as the gases of geochemical significance are different from the contaminant gases. The time history of response should identify contaminant gases, as they should slowly fade away.

J. M. Carroll is the project engineer on the cold cathode ALSEP experiment.

### 2. Atmospheric Mixing in the Lower Thermosphere

F. S. Johnson
R. R. Hodges, Jr.
W. B. Hurt

The effects of eddy mixing and other transport processes on the structure of the upper atmosphere are being studied. From the heat budget, an excess input is found above each altitude in the mesosphere and thermosphere that can only be disposed of by downward transport; neglecting large scale circulation, a world-wide average value for the eddy diffusion coefficient has been calculated. An evaluation has also been made of the large scale transport necessary to compensate for the latitudinal variation in heat input. The transport properties, both eddy mixing and large scale circulation, also affect the composition. Present investigations in this area are directed toward developing a world-wide atomic oxygen budget.

A laboratory effort is underway to evaluate the possibility of measuring atomic oxygen concentrations in the lunar thermosphere by chemical means. The concept provides for the flow of ambient gas through a reaction tube, into which a gas is titrated to react with atomic oxygen and produce luminescence. A measurement of the luminescence should be interpretable in terms of atomic oxygen concentration. The method appears potentially promising for measurements of concentrations as low as $10^{10}$ atoms $cm^{-3}$.

3. Ion Mass Spectrometer for ISIS-B Satellite

J. H. Hoffman

An ion mass spectrometer has been constructed for the ISIS-B satellite. The instrument scans the mass range 1-64 amu and measures the relative abundances of the ions collected in this mass range from the ambient ionosphere in the vicinity of the satellite. Orbital parameters of the satellite are 1400 km circular with an inclination in the range from 75 to 88°, the exact value yet to be determined.

An attitude control system in the spacecraft will allow either a cartwheel (spin axis normal to orbital plane) or spin axis aligned in the orbital plane operation.

One of the problems to be studied by this mass spectrometer experiment is the composition, energy, and distribution in time and space of the polar wind particles. The dominance of $O^+$, total ion concentrations of the order of $10^3$ ions $cm^{-3}$ (at mid-latitudes they are nearly $10^4$) at 2500 km along with $H^+$ upward streaming velocities to 10 to 15 km/sec are all features of the polar wind.

The mass spectrometer is a magnetic deflection instrument with two ion detector systems. Two ion beams emerge from the magnet after traversing paths of radii 2.00" and 0.707" and are simultaneously detected by electron multipliers and log electrometer amplifiers. A "Peaks" circuit following each amplifier detects the ion peak amplitude and transmits only this information back to earth at a large saving in telemeter bandwidth. The ion accelerating voltage is scanned over a factor of 8 in 1 second producing a scan of the mass ranges 1-8 amu and 8-64 amu, simultaneously. The sensitivity of the instrument is of the order of 1 ion $cm^{-3}$.

4. Lunar Orbital Mass Spectrometer

J. H. Hoffman

A primary scientific objective of the Mass Spectrometer Experiment is to obtain data on the composition and distribution of the lunar ambient atmosphere in the mass range 12 to 66 amu to detect the existence of an atmosphere and to study its sources, sinks, and transport mechanisms. A second goal is the detection of transient changes in composition due to venting of gases from the surface, or from man-made sources. The measurements of the lunar atmosphere will be accomplished utilizing a magnetic deflection sector-field mass spectrometer, mounted on a 24-foot boom extending from the Scientific Instrument Module (SIM) mounted in Bay 1 of the Apollo Service Module on flights 15 and 16. A plenum, that serves as the gas entrance system to the mass spectrometer, is pointed along the spacecraft velocity fector and acts as a scoop through which gases are rammed due to the motion of the spacecraft. Gas molecules emanating from the spacecraft are highly discriminated against due to the geometry of the plenum. The instrument samples the gases arriving through the plenum by ionizing them in the ion source with an electron beam generated by a hot filament. The ions are collumated into a beam and dispersed by a magnetic field into two separate collectors which detect ions in the mass ranges 12-28 and 28-66 amu. Two detection systems, one for each channel, accumulate counts which are transmitted to earth via the telemetry system. The mass spectrum is scanned by varying the ion accelerating voltage to the ion source in a step-wise manner approximating an exponential. When the counts per step are plotted against the step number, a digital representation of the mass spectrum is obtained. The amplitude of each peak in the spectrum determines the number density of the parent gas species and the position in the spectrum (step number) identifies the species.

5. Lunar Atmospheric Composition Experiment

J. H. Hoffman

The major objective of this experiment is to measure the composition of the lunar atmosphere using a magnetic sector-field mass spectrometer as part of an ELLSEP array of experiments on Apollo 17. A second objective is the detection of transient changes in composition due to venting of gases from the surface or from man made sources. Mass Spectrometers will provide the means of determining the natural distributions of gases in the lunar atmosphere; this information is essential if the sources, sinks and transport of these gases are to be understood. Since the lunar atmosphere is a classical example of an exosphere, its global structure can be used to test theories on exospheric transport, which is an important process in the terrestrial atmosphere.

The instrument samples the gases arriving at its entrance by ionizing them in the ion source with an electron beam generated by a hot filament. The ions are collumated into a beam and accelerated into a magnetic field which then separates it into three beams. Three separate collectors detect ions of mass ratios 1:12:27.4 simultaneously. The mass ranges scanned are 1-4; 12-48; 27.4-110 amu. The mass spectrum is scanned by varying the ion accelerating voltage to the ion source in a step-wise manner approximating an exponential. The stepping control system is updated by the frame sync pulse from the Central Processor located some fifty feet from the experiment. Ion counts are accumulated by a detection system, one for each of the three channels, during each of the voltage steps of the mass scan, and when plotted against step number yields a digital representation of the mass spectrum. The amplitude of each peak in the spectrum determines the number density of the parent gas species and the position in the spectrum (step number) identifies the species.

6. Rocket Probes for the F-Region

W. B. Hanson

Continued analysis of the Upper-F region rocket series (Javelin) data has utilized a least-squares curve fitting program as used on the OGO VI ion trap data to obtain ion temperature, total ion concentration, and vehicle potential. The analysis showed that the principal ion was $O^+$ up to at least 700 km with probably as much as 10% $H^+$ above that. Ion temperature results show an isothermal region of around 1400°K up to 500 km. At that point the ion temperature starts to increase and reaches 2300°K at 792 km, the maximum height. The least squares program also reveals good agreement between the linear ion trap and the logarithmic ion trap with regard to ion concentration and ion temperature. The ion concentration of the log trap falls about 3% below that of the linear trap while the ion temperature of the log trap is about 10% below that of the linear trap.

Results from the Javelin 8.53 mass spectrometer which was launched from Natal, Brazil, in June 1969 are being analysed in terms of a theoretical model that takes into account all the known processes that determine the equatorial distributions of the ions $H^+$, $He^+$, $O^{++}$ and $N^+$ above the $F_2$ peak. Dr. R. J. Moffett is cooperating in this effort.

A paper on the minor ion concentrations up to 800 km at the magnetic equator, which utilized the 8.53 data, was presented at the COSPAR meeting in Leningrad, USSR, May 1970.

To investigate the region below 300 km, two Nike-Tomahawk payloads have been prepared to launch in the early summer of 1971 which should complement the Javelin measurements. The Nike-Tomahawk instrumentation will measure ion temperature, ion concentration, electron temperature, and ion composition.

These rocket measurements and interpretations are being carried out by W. B. Hanson, R. J. Moffett, S. Sanatani, C. R. Lippincott, D. Zuccaro, and D. Frame.

7. Ionospheric Duct Detector for OGO-F

W. B. Hanson

The successful launch of OGO-F (now called OGO-VI) took place on June 5, 1969. Excellent data have been received from the duct detector since its turn-on on orbit #20. Analysis of the data has been proceeding in an orderly fashion, with the sophistication of the computer programs increasing as the quality and quantity of the incoming data increased.

Several hundred orbits of data have been analysed for ion temperature, ion concentration, and ion composition. It appears that reliable measurements of ion temperature are being made to an accuracy better than 10% (and quite possibly better than 5%) in a quiet ionosphere, but comparisons with other techniques are needed to establish this conclusively (Hanson et al., 1970).

In the dawn-dusk plane the ion temperature is observed to vary from 1000°K to 4000°K, where the higher temperatures are associated with the higher altitudes in the winter hemisphere.

Heavy ions of about mass 56 AMU, probably iron ions, are observed to be present at heights well above the $F_2$ peak at concentrations of the order of $10^2$ $cm^{-3}$. Another ion (or ions) of intermediate mass (30 AMU) and comparable concentrations is also observed, but its identification is now obscure. The heavy ions are a rather common feature of the nighttime ionosphere (Hanson and Sanatani, 1970).

Fluxes of electrons with energy greater than 10 ev of the order of $10^8$ $cm^{-2}$ $sec^{-1}$ are observed that change rather smoothly within the plasmasphere but show rapid and large variations at higher latitudes.

The duct mode performs even better than anticipated. These measurements have revealed considerable horizontal fine structure in ion concentration down to very small fractional amplitude changes. On occasion at low latitudes the ionosphere is observed to be smooth to one part in a thousand over distances of several hundred kilometers. Over the polar regions, there exist large horizontal concentration gradients.

The OGO-VI satellite has a variety of experiments which, taken together, provide a rather unified picture of the behavior of earth's ionosphere and atmosphere as a function of latitude, altitude and local time. We are cooperating with many of the appropriate experimenters to bring forth this unified picture. Additional correlation studies are being carried out with ground based experiments at Boulder, Jicamarca and Arecibo.

Dr. W. B. Hanson is Principal Investigator for this instrument. Dr. S. Sanatani and Fred Metrailer have played important roles in the data handling processes.

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Hanson, W. B., S. Sanatani, D. Zuccaro, and T. W. Flowerday, "Plasma Measurements with the Retarding Potential Analyser on OGO VI," J. Geophys. Res., 75 (28), 5483, 1970.

Hanson, W. B., and S. Sanatani, "Meteoric Ions above the $F_2$ Peak," J. Geophys. Res., 75 (28), 5503, 1970.

8. Ion Mass Spectrometer for OGO-F

W. B. Hanson

The magnetic deflection ion-mass spectrometer on OGO-VI was turned on during orbit #36, two and one half days after launch. Data were obtained for the next 20 orbits, and then the electrometer output went to zero and has remained there. Quick look data show that the spectrometer was quite sensitive, and that all modes of operation could be operated successfully.

The resulting 3000 minutes of data were analysed and compared with results of the duct detector and the other mass spectrometer on OGO-VI. There was some unknown random parameter affecting the output of this instrument causing the data to be inconsistent. Analysis was terminated in July on expiration of the contract, and a final report was submitted defining the history and results of this experiment.

Dr. W. B. Hanson is Principal Investigator for this instrument. Mr. Fred Metrailer is responsible for the data handling procedures.

9. Viking Program

W. B. Hanson

Dr. Hanson was selected to the Viking entry science team, and the instrument he suggested for the entry science, a retarding potential analyser (RPA), has been incorporated into the payload.

The RPA will be used as a multipurpose instrument. It is hoped that the following information will be derived from its measurements:

a.) The position of the solar wind shock boundary

b.) Whether or not a Chapman-Ferraro current sheet separates the ionosphere from the shocked region

c.) The electron and ion temperatures in the lower ionosphere

d.) The concentration and composition of the lower ionosphere

This information, together with that provided by the neutral mass spectrometer, should provide a reasonable basis for further theoretical work on the solar wind and Martian atmosphere interaction, which will have a direct impact on the evolution of the Martian atmosphere. In all likelihood, many of the concepts emerging from this work will also be applicable to Venus.

10. The Pioneer Interplanetary Probe Programs

R. P. Bukata

All of the UTD Pioneer 6-9 detector systems have been designed to provide co-ordinated measurements on the nature and degree of low energy ($\lesssim$ 100 MeV/nucleon) cosmic ray propagation within the magnetic field structures which define the inner solar system. They are equipped to accumulate data pertinent to the degree of anisotropy present in both the flare-initiated and quiescent cosmic ray fluxes, the energy spectra of the proton and alpha particle components of the cosmic radiation, and the temporal variations of each of these component fluxes. The detectors basically comprise a scintillation crystal encapsulated within a plastic anti-coincidence cup and utilize "aspect clock" circuitry to study cosmic ray anisotropies within the ecliptic plane to a very high degree of accuracy. In addition to the scintillation counters, Pioneers 8 and 9 also include a tri-telescope configuration of four solid-state detectors to provide anisotropy information on the propagation of low energy (3-10 MeV) cosmic ray fluxes whose incident directions of arrival at the spacecraft make angles as large as $\pm 50°$ to the ecliptic plane.

Many of the UT Dallas results from the Pioneer spacecrafts have appeared recently in the scientific literature. A partial list of these results and studies currently being undertaken would include:

(a) Studies of the heliocentric longitude density gradient. It has been shown that performing simultaneous measurements of cosmic ray intensity at different heliolongitudes enables an estimate of the azimuthal gradient of cosmic ray flux, which is essential for estimating the solar flare location as well as understanding the decay effects.

(b) Studies of the decay phase of solar flare effects. It has been shown that the decay of a flare enhancement is completely governed by the convection by the solar wind and the azimuthal gradient.

(c) Studies of the anisotropic particle propagation of solar injected cosmic radiation. It has been shown that the anisotropy observed during solar flare effects undergoes a natural three phase evolution. These three phases may be taken as:

Phase 1: Field aligned anisotropies indicative of a high order of "guiding-center" motion. The anisotropies are generally aligned along the local Archimedes spiral configuration, and thus usually appear as arriving from the west. After $\sim$1 day this high degree of particle collimation gradually becomes

Phase 2: Equilibrium anisotropies from the general Sun direction. In this phase the cosmic ray evacuation is largely under the control of the convective properties of the solar wind. This phase usually occurs between 1-4 days after the initial injection and rather quickly gives way to

Phase 3: Equilibrium anisotropies from directions close to 45° East of the satellite sun line. During this phase in the flare event, the diffusive component of the cosmic ray population becomes significant enough to cause the bulk motion of the cosmic ray magnetic field lines.

(d) Studies of low energy particle propagation during solar flare effects. Of particular interest was the "back side of the sun" solar flares of January 28, 1967 and March 30, 1969, in which detailed studies were performed utilizing data from the strategically located Pioneers 6 and 7 spacecrafts and the worldwide network of super neutron monitors.

(e) A collaborative effort with the Goddard Space Flight Center's IMP-C data resulted in a study of the long lived regions of modulated cosmic ray flux following the general spiral configuration of the interplanetary magnetic field as the field structures co-rotate with the sun.

(f) An intercomparison of the Pioneer 8 data with the UT Dallas IMP-F data initiated a fruitful study of the co-rotating electron event of July 13, 1968.

(g) A study of the time dependence and modulation of galactic alpha particles at conditions of solar minimum has indicated a velocity dependence for transient modulation phenomena, and a "quiet-time" solar-origin proton flux which is approximately equal to the galactic proton flux.

(h) Studies of the radial gradient of interplanetary cosmic radiation have indicated a small positive radial gradient [(3.5 $\pm$2)% per AU] for 124-304 MeV alpha particles, consistent with a galactic origin for this nuclear species, and a negative radial gradient for the proton flux [-(21 $\pm$5)% per AU for protons >7.5 MeV], consistent with a large solar outflow at low energies.

The Pioneer spacecraft experiments are being conducted by Drs. R. P. Bukata, K. G. McCracken (now at the University of Adelaide, Australia) and U. R. Rao (now at the Physical Research Laboratory, India). Mr. E. P. Keath is working toward a doctorate to be granted by North Texas State University.

11. The Neutron Monitor

R. A. R. Palmeira

The University of Texas at Dallas operates two super neutron monitors at Fort Churchill, Manitoba, and Dallas, Texas. The pressure corrected hourly averages from these two monitors are distributed on a regular basis to the cosmic ray community. In addition, the pressure corrected daily averages are sent each month to the Environmental Data Service of the National Oceanic and Atmospheric Administration, and are published monthly in the Solar-Geophysical Data Bulletin as part of the cosmic ray indices of solar activity.

On November 18, 1968, an increase of approximately 12% was recorded by the Churchill neutron monitor. The Dallas monitor recorded a statistically significant increase of only 1.6%. Detailed analysis of the percentage increases detected by the worldwide neutron monitor network, taking into account the asymptotic direction of viewing of each station, lead to the conclusion that the arrival of the particles at the orbit of the earth was highly anisotropic, the only stations detecting any appreciable increase being those that at the time of the solar injection were looking in the directions between 0 and 90° west of the earth-sun line. This anisotropy in the particle direction of arrival is consistent with the known location of the parent flare ($\sim$90° west) and the idealized Archimedes spiral configuration of the interplanetary magnetic field lines. Satellite measurements of the anisotropy in space, outside the influence of the earth's magnetic field, yielded an anisotropy in the 1-100 MeV energy range with the same direction of maximum intensity as found in the higher energies detected by the neutron monitors.

Another solar flare increase analyzed in detail was that which occurred on March 30, 1969. The neutron monitor counting rate increase was quite small ($\sim$5% in Churchill, and $\sim$1% in Dallas), but the high counting rates of the super-neutron monitors render even such minor increases amenable to detailed analysis. In this particular event, it could be shown that although on the whole the increase was nearly isotropic, a small anisotropy from east of the earth-sun line was present at the time of the maximum intensity. This anisotropy, however, was small so that a method developed to calculate the rigidity spectrum for isotropic increases could be used, yielding a value of $-3.9 \pm 0.1$ for the exponent of the power law rigidity spectrum.

A study of the semi-diurnal component of the cosmic ray variation has been started. Data from stations selected on the basis of their geographical location and reliability of operation will be subjected to a standard Fourier analysis, from which the true amplitude and direction of maximum of the anisotropy responsible for the semi-diurnal variation will be calculated. This calculation will be performed for the present solar cycle starting in 1964, and the rigidity dependence of the anisotropy, and its time variation with the solar cycle activity will be evaluated. These results will provide a test on current models for the semi-diurnal variation, based on cosmic-ray density gradients perpendicular to the ecliptic plane.

12. The Interplanetary Monitoring Platform (IMP) Program

R. A. R. Palmeira
F. R. Allum

The IMP F (Explorer 34) satellite was launched on May 24, 1967, into a highly eccentric geocentrical orbit, with an apogee of $31R_E$. It carried the first of a series of two UTD cosmic ray anisotropy experiments designed by F. R. Allum, W. C. Bartley, J. R. Harries, K. G. McCracken, R. A. R. Palmeira, and U. R. Rao. Since the satellite spends over 60% of its time far beyond the magnetosphere, this experiment is well suited to measure the degree of anisotropy of the galactic and solar components of the cosmic radiation in the energy range 1 to 100 MeV/nucleon. The Explorer 34 spacecraft remained in orbit until April 1969 when it descended and burned out in the atmosphere. The UT Dallas cosmic ray anisotropy experiment worked properly until that time, with the exception of the proportional counter that stopped operating in March 1968.

The IMP G (Explorer 41) satellite was launched on June 21, 1969, into a very similar orbit to that of the IMP F. It carried the second of the series of low energy cosmic ray anisotropy experiments designed and built by the cosmic ray group of The University of Texas at Dallas. To date, this satellite is still operational and the UTD cosmic ray detector is working properly since the time of the launch.

The principal conclusions drawn from all the data from these two satellites can be summarized as follows:

(a) The frequency of occurrence of solar flares capable of accelerating 1-10 MeV particles is much larger than for higher energy particles. The amount of the increase varies from a few tens of percent to several orders of magnitude.

(b) Large field aligned anisotropies (40-80%) are observed during the rise time of the proton solar events. The amplitude of the field aligned anisotropy at low energies ($\sim$1 MeV) is independent of the rise time of the flare event, and the position of the parent flare, but depends on the particle energy, the anisotropy being larger at lower particle energies.

(c) During the early part of the decay of the proton flare event ($T<4$ days), the cosmic-ray population exhibits radial equilibrium anisotropy varying inversely with the particle velocity and directly with the solar wind velocity. The equilibrium anisotropy during this period is due to convective removal of the particles by the radially moving solar wind.

(d) During late times in the decay of the flare event ($T>4$ days), the direction of the equilibrium anisotropy is from 45° East of the earth-sun line. This anisotropy can be interpreted in terms of a positive density gradient of cosmic ray particles being set up near the orbit of the earth. This gradient then drives a diffusive current along the interplanetary magnetic field lines toward the sun, which, when combined with the convective removal, produces the observed eastern anisotropy. The amplitudes of the anisotropy during the decay of the event are of the order of 5-15%.

(e) The crossing of magnetic sector boundaries seems to prolong the non-equilibrium anisotropy of solar proton events. The equilibrium anisotropy is not, however, affected by these boundary crossings.

(f) The time profiles of low energy solar proton events show complicated structures during both the onset and decay phase of the event. Whereas higher energy particles show a smooth exponential decay, the lower energy particles show complicated features and seem to decay with a much slower time constant. This slower decay is explainable in terms of a larger influence of the azimuthal density gradient at lower energies.

(g) The probability of observing electrons released by a solar flare is a strong function of the solar longitude of the parent flare. This probability is a maximum for flares located $\sim$45°W on the solar disk. This evidence is in accord with the hypothesis that the electrons propagate along the Archimedes spiral interplanetary magnetic field.

(h) The onset of the enhancement for electrons of energies $\gtrsim$70 keV takes place about 20 minutes earlier than the onset of 1 MeV protons. The time dispersion is consistent with their velocity of travel along the field lines. The rise time of solar electron events is shorter compared to those of the proton events.

(i) The solar electrons of energies $\gtrsim$70 keV exhibit anisotropies of lesser magnitude than those of low energy protons. Even when large electron anisotropies are seen at the onset of a solar event, the electron population relax toward isotropy within 1-2 hours from the onset.

(j) The decay of the electron anisotropy is in good accord with a diffusive theory developed by Fisk and Axford.

(k) At late times, the solar electron fluxes exhibit equilibrium anisotropies, whose properties are in good accord with existing theories. The existence of an equilibrium anisotropy indicates that the electron population leaves the solar system through convection alone.

(l) The equilibrium anisotropy very late in the solar electron events is very frequently from the east of the earth-sun line. As is the case for protons, this suggests the establishment of an electron positive density gradient near the orbit of the earth.

(m) A new type of particle increase was found in the less than 10 MeV energy range. This increase occurs within a few minutes of a magnetic storm sudden commencement, lasts less than one hour, and is restricted to energies less than 4 MeV. During the period May 1967 - June 1968, eleven such increases were observed. Among the four largest events, three displayed a very definite bi-directional anisotropy during the maximum enhancement. An explanation for these increases has been proposed in terms of low energy particles trapped in, and swept by the advancing shock front responsible for the sudden commencement.

13. Modular Auroral Probe Rocket Program

W. J. Heikkila

During the past several years a Nike-Apache rocket investigation of auroral zone phenomena has been carried out using modular payloads with recovery by parachute for subsequent reflight. Four payloads have been built, and a total of eight flights have been achieved. Unfortunately the parachute system malfunctioned in three flights, leaving only one payload in good condition. However, some of the instrumentation from two other payloads can be refurbished. Results are being analyzed for publication, and also for a Ph. D. dissertation.

At the present time a larger rocket, the Black Brant V, is being instrumented for further auroral studies during the winter 1971-72 in conjunction with passes by the ISIS-B satellite, and possibly the NASA instrumented aircraft. The modular approach is again being used, incorporating many of the Nike-Apache instruments. The larger size of the rocket also permits flying several back-up instruments from UTD satellite programs, namely Dr. Heikkila's soft particle spectrometer and Dr. Hoffman's ion mass spectrometer from ISIS-B, and Dr. Hanson's ion trap from OGO-F. Two flights are planned, dependent on successful payload recovery.

14. Soft Particle Spectrometer

The ISIS-I satellite carried a soft particle spectrometer which provided excellent data during the period February 2-October 26, 1969. (Heikkila et al, 1970). Final checkout of the ISIS-B satellite carrying a similar spectrometer is now in progress, with launch scheduled for March, 1971.

Preliminary results have been published on some of the ISIS-1 data. The photoelectron escape along mid-latitude geomagnetic field lines is clearly revealed (Heikkila, 1970). The detailed properties of the flux, such as total particle flux, energy spectrum, angular distribution, nighttime fluxes from the conjugate hemisphere, and the dependence on solar zenith angle are at present being compared with theoretical predictions made by other groups, especially Dr. A. F.

Nagy at the University of Michigan and Dr. P. Banks at the University of California at San Diego.

A strong flux of 100 ev electrons and several hundred ev protons at high latitudes (75°-80°) during the daytime have been identified as solar wind plasma penetrating via the magnetospheric cusps (Heikkila and Winningham, 1971). This is exciting new evidence for open magnetospheric models. This flux seems to be the cause of many daytime high-latitude geophysical phenomena such as aurora, electromagnetic noise, and geomagnetic fluctuations.

Nighttime auroral fluxes are observed on every pass, although the intensity and location depend on the level of activity. The flux often hardens noticeably at the center of an auroral form (Heikkila, 1970). A comparison with our rocket observations is being made, particularly as part of a Ph. D. dissertation project.

A surprising observation is that of intense fluxes of kilovolt electrons and protons over the equator at night, in the 600 to 1000 km range (Heikkila, 1971). The source of these is not known, although there is a possibility that they are convected down from the inner Van Allen belt by electric fields of tidal or magnetospheric origin. Correlation of such fluxes with equatorial ionospheric structure as observed with the topside sounder is being pursued with Dr. Leroy Nelms of the Communications Research Center, Ottawa, Canada, and Dr. Raghava Rao of Ahmedabad, India.

15. Laboratory Study of Plasma Probes

The evaluation of d.c. and a.c. plasma probes in a laboratory plasma similar to D and E region ionospheric plasma is continuing. The effect of Langmuir probe surface contamination has been demonstrated (Bunting and Heikkila, 1970), as a clear warning to the users of such probes in ionospheric applications. The physics of the ion sheath has been studied through the transient motions produced by step changes in probe potential (Bunting and Heikkila, 1971); this work also is the basis of a Ph.D. dissertation completed by Bunting in November 1970. Some work is continuing on the radio frequency properties of probes, as part of a Ph. D. dissertation by Jens Tarstrup.

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## IV.

## Other Support for NASA

The University of Texas at Dallas provides additional support to NASA in several ways. Dr. W. B. Hanson serves on the Ionospheres and Radio Physics Subcommittee of NASA's Space Science Steering Committee. Dr. F. S. Johnson is a member of the Lunar and Planetary Missions Board and the Research and Technology Committee on Space Vehicles of NASA Headquarters, and the Group for Lunar Exploration Planning of the Manned Spacecraft Center; he has also been a member of the Planetary Atmospheres and the Ionospheres Subcommittees of the Space Science Steering Committee, Chairman of the Lunar Atmosphere Measurements team, and a member of the Voyager Capsule Advisory Group. Dr. C. E. Helsley is serving on the Geophysical Ad Hoc Site Selection Committee for Apollo 15-17. Other staff members of the Center have served on various NASA committees and have responded in other ways to NASA needs in providing professional advice when requested. Cooperative projects have been carried out with several NASA Centers.

V.

## Contracts and Grants

"For Continuing Operating Support of the Dallas and Ft. Churchill Super-Neutron Monitor Stations," NSF Grant GA-10940, R. A. R. Palmeira.

"Measurement of the Degree of Anisotropy of the Cosmic Radiation Using the IMP Space Vehicle," NASA Contract NAS5-9075, K. G. McCracken and R. A. R. Palmeira.

"A Soft-Particle Spectrometer for the ISIS-A Satellite," NASA Contract NAS5-9112, W. J. Heikkila.

"Investigations into the Mechanism and Rates of Atmospheric Mixing in the Lower Thermosphere," NASA Grant NGR44-004-026, F. S. Johnson.

"For Continuation of Laboratory Plasma Probe Studies," NASA Grant NGR44-004-030, W. J. Heikkila.

"Rocket Probes for the Upper F-Region," NASA Contract NSR44-004-029, W. B. Hanson and T. W. Flowerday.

"Develop Payloads for a Systematic Rocket Study of Auroral Zone Disturbances," NASA Contract NSR44-004-041, W. J. Heikkila.

"Ionospheric Duct Detector," NASA Contract NAS5-9311, W. B. Hanson and T. W. Flowerday.

"Cold Cathode Gauge for Apollo Lunar Surface Experiment," NASA Contract NAS9-5964, F. S. Johnson.

"Composition Measurement of the Topside Ionosphere Using a Magnetic Mass Spectrometer," NASA Contract NAS5-11003, J. H. Hoffman.

"A Soft-Particle Spectrometer for the ISIS-B Satellite," NASA Contract NAS5-11011, W. J. Heikkila.

"For Processing and Interpretation of Data for Pioneer C," NASA Contract NAS2-4674, R. P. Bukata, U. R. Rao and K. G. McCracken.

"Mass Spectrometer for Apollo 15 and 16," NASA/MSC Contract NAS9-10410, J. H. Hoffman.

"Participation in the Science Planning for the Viking 1975 Missions in the Area of Entry Science," NASA/Langley Contract NAS1-9699, W. B. Hanson.

"Grille Spectrometer Measurements of Night Sky Emmissions," NSF Grant GA-18767, B. A. Tinsley.

"Lunar Atmospheric Composition Experiment on ALSEP - Lunar Mass Spectrometer Analyzer Apollo 17," Sub-Contract 830 with Bendix/NASA/MSC, J. H. Hoffman.

VI.

## Publications

1. Atmospheric and Space Sciences Division

Allum, F. R., R. A. R. Palmeira and U. R. Rao, "Low Energy Proton Increases Associated with Geomagnetic Storms Sudden Commencements," Proc. of the Eleventh Int. Conf. on Cosmic Rays, Budapest; to be published 1970.

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Balasubrahmanyan, V. K., E. C. Roelof, R. P. Bukata and R. A. R. Palmeira, "Co-Rotating Modulations of Cosmic Ray Intensity Detected by Spacecrafts Separated in Solar Azimuth," Acta Physica Hungarica, 1970.

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VIII.

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Carter, J. L., "Results of Apollo 11 Sample Analysis," Dallas Metropolitan Philosophical Society, Dallas, Texas, January 14, 1970; Dallas Gem and Mineral Club, Dallas, Texas, March 10, 1970; Dallas Independent School District, Dallas, Texas, March 21, 1970; Texas Instruments Gem and Mineral Club, Dallas, Texas, April 14, 1970

Carter, J. L., "Romance of the Moon," Dallas Pigeon Club Auxiliary, Dallas, Texas, January 31, 1970.

Carter, J. L., "Geological History of the Apollo Samples," Bryan Adams High School Science Fair, Dallas, Texas, March 3, 1970; Northwood Junior High School, Richardson, Texas, May 1970; Dallas Health and Science Museum, Dallas, Texas, June 16, 1970.

Carter, J. L., "Scientific Findings of Apollo Samples," College Science Improvement Program, The University of Texas at Dallas, Dallas, Texas, May 8, 1970.

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Carter, J. L., "Why Go to the Moon?" Northwood Junior High School, Richardson, Texas, May 1970.

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Rindler, W., "Quasars, Pulsars and Other Recent Discoveries in Cosmology," East Dallas Exchange Club, Dallas, Texas, October 6, 1970.

IX.

Seminars Presented by U. T. D. Faculty and Staff

Cahen, M., "Pinched Manifolds, Comparison Theorems, etc.," M&MP Seminar, Dallas, Texas, April 7, 1970.

Cahen, M., "The Theory of Symmetric Lorentzian Spaces," Lectures at Rutgers University, New Brunswick, N.J., April 18-25, 1970.

Cahen, M., "Bonnet Theorem," M&MP Seminar, Dallas, Texas, May 19, 1970.

Cahen, M., "Separation Theorems in Pseudo-Reimannian Symmetric Spaces," M&MP Seminar, Dallas, Texas, May 22, 1970.

Cahen, M., "Comparison Theorems (Rauch, Toponogov)," M&MP Seminar, Dallas, Texas, May 26, 1970.

Cahen, M., "Green's Functions in DeSitter Space," M&MP Seminar, Dallas, Texas, May 29, 1970.

Cahen, M., "Fantasy about SL(2,R)," Lecture Series for M&MP Seminars, Dallas, Texas, June 15-19, 1970.

Carter, James L., and Charles E. Helsley (with Robert F. Sippel and Alexander B. Spencer of the Mobil Research and Development Corporation), "Results of Preliminary Analysis of Apollo 11 Samples," Geosciences Seminar, Dallas, Texas, January 20, 1970.

Collins, C. B., "Atomic and Molecular Collisions," Institute of Physics of the State Nuclear Energy Committee, Bucharest, Romania, July 10, 1970.

Collins, C. B., "A Computer-Controlled System for the Collection of Afterglow-Data," Institute of Physics of the State Nuclear Energy Committee, Bucharest, Romania, July 18, 1970.

Collins, C. B., "Use of Atomic Screening Parameters to Obtain Analytic Approximation for the Cross Sections of Inert Gases," Institute of Physics of the State Nuclear Energy Committee, Bucharest, Romania, July 25, 1970.

Fenyves, E., "An Experiment on Deep Inelastic Electron Proton Scattering. What Can We Learn About Proton Structure," Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, January 12, 1970.

Fenyves, E., "Proposal for a Deep Inelastic e-p Experiment," Laboratory of Nuclear Studies, Cornell University, Ithaca, New York, January 19, 1970.

Fenyves, E., "Search for Quarks in Cosmic Rays," Department of Physics, Temple University, Philadelphia, Pennsylvania, February 23, 1970.

Hanson, W. B., "Plasma Measurements with the Retarding Potential Analyser on OGO VI," Rice University, Houston, Texas, February 12, 1970.

Hanson, W. B., "Planetary Atmospheres," University of Idaho, Moscow, Idaho, October 30, 1970.

Heikkila, W. J., "The Magnetosphere and its Relation to Ionospheric and Auroral Phenomena," The University of Texas at El Paso Summer Institute - Physics of the Upper Atmosphere, El Paso, Texas, August 3-14, 1970.

Heikkila, W. J., "The Topside Ionosphere," The University of Texas at El Paso Summer Institute - Physics of the Upper Atmosphere, El Paso, Texas, August 3-14, 1970.

Heikkila, W. J., "Auroral Particles," Physics Department, Southern Methodist University, Dallas, Texas, October 16, 1970.

McClure, J. P., "A Survey of Incoherent Scatter Temperature Results," DASS Seminar, Dallas, Texas, September 30, 1970.

Midgley, J. E., "Structure of the Ionosphere," The University of Texas at El Paso Summer Institute - Physics of the Upper Atmosphere, El Paso, Texas, August 3-4, 1970.

Michael, F. Y., "General Geology of Egypt with Emphasis on the Evolution of the Nile River," Geosciences Seminar, Dallas, Texas, May 5, 1970.

Ozsváth, István, "Spatially Homogeneous World Models," The University of Oklahoma, Norman, Oklahoma, April 16, 1970.

Ozsváth, István, "Expanding Universes," The University of Hamburg, Germany, July 17, 1970.

Rao, U. R., "X-Ray Fluxes from Discrete Sources," DASS Seminar, Dallas, Texas, October 13, 1970.

Rindler, Wolfgang, "Recent Developments in General Relativity," Southern Methodist University, Dallas, Texas, February 27, 1970.

Rindler, Wolfgang, "A Gravitationally Induced (Machian) Magnetic Field," University of Vienna, Austria, July 21, 1970.

Rindler, Wolfgang, "Old and New Results in Connection with Mach's Principle," The University of Oklahoma, Norman, Oklahoma, November 20, 1970.

Robinson, Ivor, "Radiation and Motion in General Relativity," Series of Seminars, Tel-Aviv University, Tel-Aviv, Israel, January and February 1970.

Robinson, Ivor, "The Formal Analogies between the Gravitational and Electromagnetic Fields," Tel-Aviv University, Tel-Aviv, Israel, January 1970.

Robinson, Ivor, "Gravitational Radiation," Weizmann Institute of Science, Rehovoth, Israel, February, 1970.

Robinson, Ivor, "Exact Solutions of Einstein's Equations," The Technion, Haifa, Israel, February, 1970.

Robinson, Ivor, "Motion and Radiation in General Relativity," Series of Seminars, Collège De France, Paris, France, June 1970.

Robinson, Ivor, "Motion of Singularities in General Relativity," King's College, London, England, July 13, 1970.

Sanatani, S., "Plasma Measurements with the Retarding Potential Analyzer on OGO 6," Physical Research Laboratory, Ahmedabad-9, Gujarat, India, August 12, 1970.

Sanatani, S., "Meteoric Ions above the $F_2$ Peak," Physical Research Laboratory, Ahmedabad-9, Gujarat, India, August 13, 1970.

Sanatani, S., "Plasma Measurements in the Ionosphere with Rocket Borne Probes," Physical Research Laboratory, Ahmedabad-9, Gujarat, India, August 14, 1970.

Shaw, M. J., "Recent Developments in the Study of Penning Ionization," DASS Seminar, Dallas, Texas, November 10, 1970.

Wells, W. E., "Stabilization Rate Studies in the Helium Afterglow," DASS Seminar, Dallas, Texas, September 23, 1970.

X.

Seminars Presented by Visiting Scientists

Avé Lallemant, Dr. Hans G., "Natural and Experimental Deformation of Peridotite," April 14, 1970, Rice University, Houston, Texas.

Beall, Arthur O., "New Results of Deep Sea Drilling in the Gulf of Mexico," May 26, 1970, Continental Oil Company, Ponca City, Oklahoma.

Bergmann, Dr. P. G., "Phase Integrals in 'Pathological' Phase Spaces," November 19, 1970, Syracuse University, Syracuse, New York.

Bichteler, Dr. Klaus, "On Integration," October 1, 1970, The University of Texas, Austin, Texas.

Bowen, Richard L., "Variations in Oceanic Salinity, Biology, Hypsometry, and Submarine Geomorphology during the past 300 Million Years," October 14, 1970, University of Southern Mississippi, Hattiesburg, Mississippi.

Braithwaite, Philip, "Sediment-Framework Organism Relationships in Three Areas of Recent Carbonate Reef Development," March 31, 1970, Sun Oil Production Company, Richardson, Texas.

Brett, Dr. Robin, "Scientific Findings from the Apollo 11 and 12," April 7, 1970, NASA Manned Spacecraft Center, Houston, Texas.

Browne, Professor J. C., "Inelastic Scattering of Fast Electrons by Diatomic Molecules," May 13, 1970, The University of Texas at Austin, Austin, Texas.

Burchfiel, Dr. B. C., "Tectonic Framework of the Southwestern United States and its Relation to Plate Tectonics," February 13, 1970, Rice University, Houston, Texas.

Chaney, Dr. Roy, "The Electronic Structure of Solids by Method of Tight Binding," February 6, 1970, University of Wisconsin, Madison, Wisconsin.

Cloud, Preston, "Biospheric, Atmospheric, and Lithospheric Evolution on the Primitive Earth," October 23, 1970, University of California, Santa Barbara, California.

Davis, Dr. James R., "Sedimentation of the Pliocene Sandstone in the Santa Barbara Channel, California," May 8, 1970, Phillips Petroleum Company, Bartlesville, Oklahoma.

Donahue, Dr. T. M., "Trouble with the Green Line," April 29, 1970, University of Pittsburgh, Pittsburgh, Pennsylvania.

Dowden, Dr. R. L., "VLF Emissions from the Magnetosphere," September 16, 1970, University of Colorado, Boulder, Colorado and New Zealand.

Eather, Dr. R. H., "The Ring Current as a Source for Proton Auroras," July 1, 1970, Boston College, Chestnut Hill, Massachusetts.

Ehlers, Dr. Jürgen, "Axioms for General Relativity in Terms of Test Particle Motions," May 19, 1970, The University of Texas, Austin, Texas.

Empedocles, Dr. Phillip, "An Integral Approach to the Calculation of Molecular Interactions," February 3, 1970, University of California, Berkeley, Berkeley, California.

Fenyves, Dr. Ervin, "Experimental Results of the Search for Quarks in Cosmic Rays," February 9, 1970, University of Pennsylvania, Philadelphia, Pennsylvania.

Fontheim, Dr. E. G., "The Problem of the Falling Nighttime Protonosphere," May 6, 1970, The University of Michigan, Ann Arbor, Michigan.

Freeman, Dr. M., "Research in Tectonophysics," March 17, 1970, Texas A & M University, College Station, Texas.

Geroch, Dr. Robert, "Multipole Moments," October 8, 1970, Center for Relativity, The University of Texas, Austin, Texas.

Girdler, Dr. Ronald, "The Birth of an Ocean: Recent Geophysical Studies of the Gulf of Aden, Red Sea, and Gregory Rift," November 2, 1970, University of Newcastle upon Tyne, England.

Goff, Dr. Ian, "Load Induced Earthquakes at Lake Kariba," May 27, 1970, University of Alberta, Edmonton, Canada.

Gold, Professor Thomas, "Pulsars," February 17, 1970, Center for Radio Physics and Space Research, Cornell University, Ithaca, New York.

Guth, Professor Eugene, "History of General Relativity," February 16, 1970, Oakridge National Laboratory, Oakridge, Tennessee.

Hare, Dr. P. E., "Optical Isomers of Amino Acids in Recent and Ancient Sediments," January 9, 1970, Geophysical Laboratory, Carnegie Inst., Washington.

Hemleben, Dr. Christoph, "Scanning Electron Microscopy of Foraminiferal Wall Structure," March 10, 1970, Geologic-Paleontologic Institute of the University of Tübingen, West Germany.

Herczeg, Professor Tibor J., "Close Binary Systems," May 25, 1970, The University of Oklahoma, Norman, Oklahoma.

Holdaway, Dr. Michael J., "Stability of Aluminum Silicates and Their Bearing on Metamorphic Petrology," March 3, 1970, So. Meth. Univ., Dallas, Texas.

Jodry, R. L., "Reef Development on the East Coast of the Andros Island, Bahamas," May 19, 1970, Sun Oil Production Company, Richardson, Texas.

Kálmán, Professor Gábor, "Pulsars in Strong Magnetic Fields," June 24, 1970, Brandeis University, Boston, Massachusetts.

Kattawar, Dr. George W., "Flux and Polarization of Radiation Reflected From Venus," February 4, 1970, Department of Physics, Texas A & M University, College Station, Texas.

Korn, Professor G. A., "New Techniques for All-Digital and Hybrid Simulation," April 23, 1970, Department of Electrical Engineering, University of Arizona, Tucson, Arizona.

Liebenberg, Donald H., "Coronal Observations and the 1970 Total Solar Eclipse," March 23, 1970, Member, Los Alamos Scientific Laboratory, University of California, Berkeley, Berkeley, California.

Lin, Professor C. C., "Optical Quenching of the Luminescence in the Photo-Hall Effect in Zinc Sulfide and Cadmium Sulfide Crystals," March 4, 1970, Department of Physics, University of Wisconsin, Madison, Wisconsin.

MacDonald, Dr. Gordon J. F., "Environmental Management," November 11, 1970, Environmental Quality Control Council, Washington, D. C.

Mantzner, Dr. Richard, "Dissipation of Anisotropy in Homogeneous Cosmologies," February 24, 1970, Wesleyan University, Middletown, Connecticut.

McCracken, Dr. K. G., "Cosmic Ray Propagation in the Solar System; Vintage 1970," September 2, 1970, Commonwealth Scientific Industrial Research Organization, Port Melbourne, Australia.

McKay, Dr. David S., "Origin of Lunar Fines and Microbreccia," March 24, 1970, NASA Manned Spacecraft Center, Houston, Texas.

Mange, P., "OGO-4 Satellite Observations of the Far Ultraviolet in the Atmosphere from 100 to 10,000 km," October 20, 1970, The E. O. Hulbert Center for Space Research, Naval Research Laboratory, Washington, D. C.

Mann, Dr. John, "Modern Stratigraphic Correlation," January 29, 1970, University of Illinois, Urbana, Illinois.

Mann, Dr. John, "The Ancient Mississippi River," January 30, 1970, University of Illinois, Urbana, Illinois.

Minear, Dr. John W., "Thermal Regime of a Downgoing Slab and New Global Tectonics," February 24, 1970, Research Triangle Institution, Durham, North Carolina.

Moffett, Dr. Roy, "Ion Distributions in the Topside Equatorial Ionosphere," September 8, 1970, Department of Applied Mathematics, University of Sheffield, Sheffield, England.

Mulliken, Professor R. S., "Energy Levels of the Xenon Molecule," March 26, 1970, University of Chicago, Chicago, Illinois.

Parr, Dr. Christopher, "Computer Animated Films of Molecular Dynamics in Chemical Reacting Systems," October 5, 1970, Chemistry Department, University of Toronto, Toronto, Canada.

Pottie, Dr. R. F., "Mass Spectrometric and Optical Measurements of Helium Metastable Atoms in the Negative Glow," March 4, 1970, Division of Chemistry, National Research Council of Canada, Ottawa, Canada.

Ramakrishnan, Dr. Alladi, "The Role of Relativity in Quantum Mechanics," June 12, 1970, Director, Institute of Mathematical Sciences, Madris, India.

Rittenberg, Dr. Vladimir, "Dual Amplitudes for n Pions," August 26, 1970, Stanford Linear Accelerator Center, Palo Alto, California.

Rundel, Robert, "Laboratory Investigation of Destruction Mechanisms of $H^-$ in Stellar Photospheres," May 20, 1970, Rice University, Houston, Texas.

Russell, Kenneth L., "Geochemistry of the Sediment-Sea Water System," January 23, 1970, Cities Service Oil Company, Exploration & Production Research, Tulsa, Oklahoma.

Scholle, Peter, "Sedimentology, Diagenesis and Regional Tectonics of the Monte Antola Flysch, Northern Appennides, Italy," June 2, 1970, Cities Service Research Lab, Tulsa, Oklahoma.

Stebbings, Professor R. F., "Oxygen Ion Collisions of Interest in Aeronomy," January 28, 1970, Department of Space Science, Rice University, Houston, Texas.

Spencer, Dr. Alexander B., "Petrology of Alkalic Igneous Rocks of Uvalde County, Texas," February 20, 1970, Mobil Research and Development Corporation, Dallas, Texas.

Tanaka, Dr. Yoshio, "Absorption Spectra of Rare Gas Molecules in the Vacuum-uv Region," March 26, 1970, Aeronomy Laboratory, AFCRL, Massachusetts.

Trümper, Dr. Manfred, "Liouville's Equation for Ellipsoidal Distribution in General Relativity," May 21, 1970, Texas A & M Univ., College Station, Texas.

Veith, Gilman D., "Organochlorine Chemistry in Natural Waters," November 5, 1970, Water Chemistry Laboratory, The University of Wisconsin, Madison, Wisconsin.

Wilson, Kent, "Laser-Molecular Beam Photodissociation of Molecules," April 8, 1970, University of California, San Diego, California.

Wrenn, Dr. Gordon, "Langmuir Probe Studies of the Ionosphere," January 27, 1970, Mullard Space Science Laboratory, University College, London, England.

Zartman, Dr. Robert E., "Radiometric Age of the Quincy Type of Granite From Eastern Massachusetts or Is Eastern Massachusetts an Exotic Block with Respect to the Rest of New England?," April 28, 1970, U. S. Geological Survey, Denver, Colorado.

Faculty and Staff, The University of Texas at Dallas

Abreu, Mr. V. J. (Research Scientist)

Adair, Mr. Carlos H. (Technical Assistant V)

Allum, Dr. F. R. (Assistant Professor)

Anschutz, Mr. LeRoy D. (Technical Staff Assistant IV)

Armstrong, Mrs. Helen L. (Secretary)

Baag, Mr. Czang-Go (Research Scientist)

Bayley, Mrs. Carol A. (Computer Programmer Assistant)

Bernhardt, Mr. Brian M. (Instrument Maker Supervisor)

Bickel, Mr. Richard L. (Research Engineer Associate V)

Blevins, Mrs. Wanda J. (Technical Staff Assistant I)

Blevins, Mr. Virgil A. (Research Engineer Associate V)

Booth, Mrs. Norma L. (Research Assistant II)

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Bunting, Dr. William D. (Research Scientist Associate III)

Burton, Mr. Rhett (Research Scientist)

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Carlin, Mr. Gary M. (Technical Staff Assistant III)

Carnahan, Mr. Joe B. (Mechanical Designer II)

Carroll, Mr. James M. (Research Engineer Associate V)

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Chaipayungpun, Mr. White (Research Scientist)

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Chang, Mr. C. (Research Scientist)

Christensen, Dr. Andrew B. (Research Associate)

Cloyd, Miss Lisa L. (Laboratory Assistant II)

Coleman, Mr. Jerry L. (Technical Staff Assistant IV)

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Dugan, Mrs. Beverly R. (Statistical Clerk II)

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Eaker, Mr. Nick (Research Engineer Associate V)

Edmonson, Mr. Dave B. (Administrative Service Officer)

Fenyves, Dr. E. (Visiting Professor)

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Lintner, Miss Linda C. (Technical Staff Assistant II)

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Martinez-Hernandez, Mr. Enrique (Research Scientist)

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Mills, Mr. J. M. Jr. (Research Scientist)

Mitchell, Dr. Brian J. (Research Associate)

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Montgomery, Dr. Robert E. (Lecturer)

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Nation, Mr. Joseph B. (Research Scientist Associate II)

Neff, Mr. Henry Judson (Research Engineer Associate)

Newport, Mr. Leo (Research Scientist)

Nutter, Mr. Jay C. (Instrument Maker II)

Ozsvath, Dr. Istvan (Professor)

Padovani, Mrs. Elaine R. (Research Scientist)

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Patrick, Miss Pat L. (Research Assistant II)

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Porath, Dr. Hartmut (Assistant Professor)

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Rogillio, Mr. Syrrel J. (Technical Staff Assistant III)

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Salsbury, Mrs. Faith E. (Laboratory Assistant II)

Sanatani, Dr. Supriya (Research Associate)

Scott, Mr. David A. (Technical Staff Assistant V)

Selva, Mr. Felipe (Research Engineer Associate II)

Sharber, Mr. James R. (Research Scientist Assistant II)

Shaw, Dr. Michael J. (Research Scientist)

Shippy, Mr. Chester L. (Research Engineer Associate III)

Shu, Miss Ginlin (Research Scientist)

Simmons, Mr. Charlie L. (Research Scientist Assistant III)

Simpson, Mr. George E. (Instrument Maker Supervisor)

Smith, Mr. Ed H. (Research Engineer Associate)

Smith, Mr. J. B. (Research Engineer Associate V)

Smith, Mr. Charles C. (Research Scientist)

Steiner, Miss Maureen B. (Research Scientist Assistant II)

Sterling, Mr. Donald (Research Scientist Associate I)

Stokes, Mr. Gordon A. (Research Engineer Associate II)

Summers, Mrs. Linda M. (Statistical Clerk I)

Swaim, Mr. Loyd A. (Technical Staff Assistant V)

Taira, Mr. Asahiko (Research Scientist)

Tarstrup, Mr. Jens (Research Scientist Associate V)

Taylor, Mr. H. C. Jim (Research Scientist)

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Tipton, Mr. Delaine G. (Research Engineer Associate IV)

Toney, Mr. James B. (Technical Staff Assistant V)

Turner, Mr. Richard Y. (Draftsman II)

Umpierre-Urquhart, Mr. Mirta (Research Associate)

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Wright, Mr. Willie W. (Research Engineer Associate V)

York, Mr. Dennis R. (Program Manager)

Younse, Mr. Jack M. (Research Engineer Associate V)

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